



Understanding Electronics Components

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This book is meant for those people who want to create electronic devices with their own hands. All components are illustrated and the circuit-symbol is explained in detail. Both simple and complex examples are provided for the beginners. These include resistors, capacitors, transformers, transistors, integrated circuits, etc and each has its own symbol to represent it in an electrical or electronic diagram - called a circuit diagram. In order to understand how a certain device functions, it is necessary to know each symbol and the characteristics of the component. These are the things we will be covering in this book.



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1. Resistors

Resistors are the most commonly used component in electronics and their purpose is to create specified values of current and voltage in a circuit. A number

of different resistors are shown in the photos. (The resistors are on millimeter paper, with 1cm spacing to give some idea of the dimensions). Photo 1.1a shows some low-power resistors, while photo 1.1b shows some higher-power resistors. Resistors with power dissipation below 5 watt (most commonly used types) are cylindrical in shape, with a wire protruding from each end for connecting to a circuit (photo 1.1-a). Resistors with power dissipation above 5 watt are shown below (photo 1.1-b).

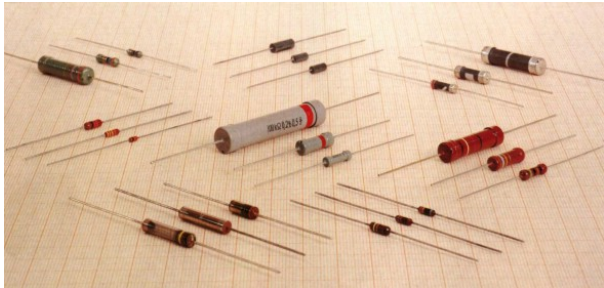


Fig. 1.1a: Some low-power resistors



Fig. 1.1b: High-power resistors and rheostats

The symbol for a resistor is shown in the following diagram (upper: American symbol, lower: European symbol.)

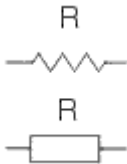


Fig. 1.2a: Resistor symbols

The unit for measuring resistance is the **OHM**. (the Greek letter Ω - called Omega). Higher resistance values are represented by "k" (kilo-ohms) and M (meg ohms). For example, 120 000 Ω is represented as 120k, while 1 200 000 Ω is represented as 1M2. The dot is generally omitted as it can easily be lost in the printing process. In some circuit diagrams, a value such as 8 or 120 represents a resistance in ohms. Another common practice is to use the letter E for resistance in ohms. The letter R can also be used. For example, 120E (120R) stands for 120 Ω , 1E2 stands for 1R2 etc.

1.1 Resistor Markings

Resistance value is marked on the resistor body. Most resistors have 4 bands. The first two bands provide the numbers for the resistance and the third band provides the number of zeros. The fourth band indicates the tolerance. Tolerance values of 5%, 2%, and 1% are most commonly available.

The following table shows the colors used to identify resistor values:

COLOR	DIGIT	MULTIPLIER	TOLERANCE	TC
Silver		x 0.01 Ω	$\pm 10\%$	
Gold		x 0.1 Ω	$\pm 5\%$	
Black	0	x 1 Ω		
Brown	1	x 10 Ω	$\pm 1\%$	$\pm 100 \cdot 10^{-6}/K$
Red	2	x 100 Ω	$\pm 2\%$	$\pm 50 \cdot 10^{-6}/K$
Orange	3	x 1 k Ω		$\pm 15 \cdot 10^{-6}/K$
Yellow	4	x 10 k Ω		$\pm 25 \cdot 10^{-6}/K$
Green	5	x 100 k Ω	$\pm 0.5\%$	
Blue	6	x 1 M Ω	$\pm 0.25\%$	$\pm 10 \cdot 10^{-6}/K$
Violet	7	x 10 M Ω	$\pm 0.1\%$	$\pm 5 \cdot 10^{-6}/K$
Grey	8	x 100 M Ω		
White	9	x 1 G Ω		$\pm 1 \cdot 10^{-6}/K$

** TC - Temp. Coefficient, only for SMD devices

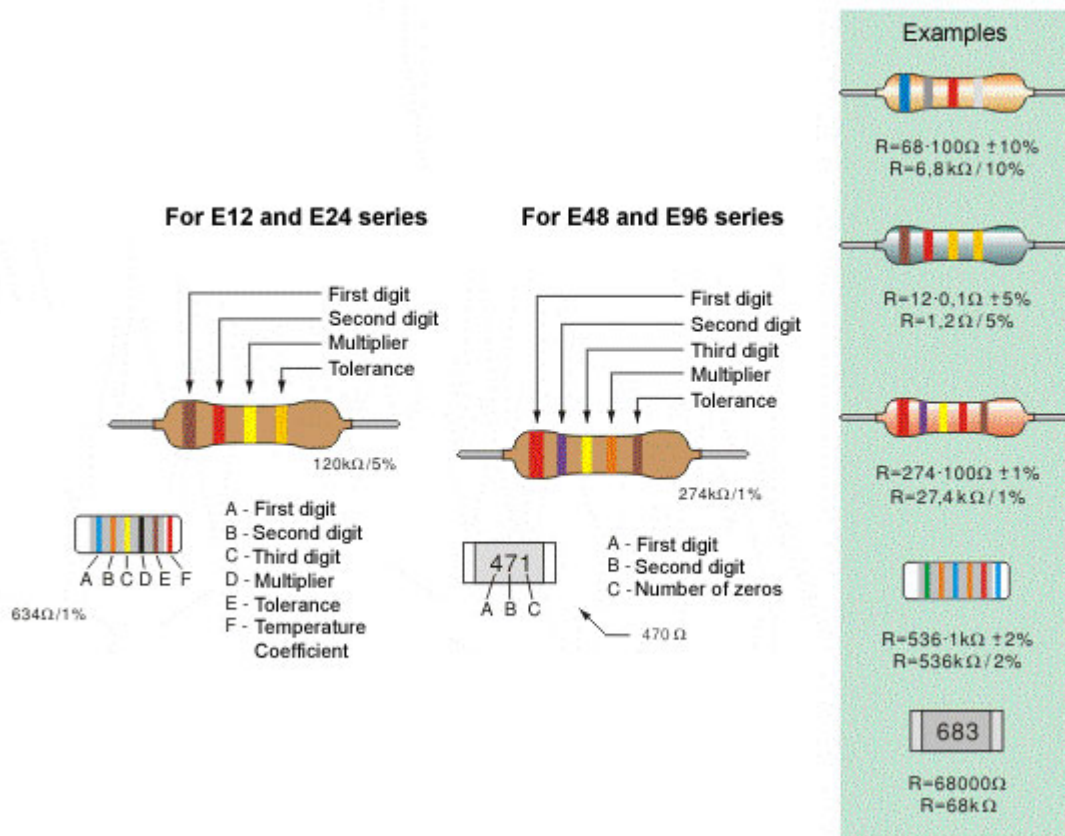


Fig. 1.2: b. Four-band resistor, c. Five-band resistor, d. Cylindrical SMD resistor, e. Flat SMD resistor

The following shows all resistors from 0R1 (one tenth of an ohm) to 22M:

1R0	10R	100R	1k0
1R2	12R	120R	1k2
1R5	15R	150R	1k5
1R8	18R	180R	1k8
2R2	22R	220R	2k2
2R7	27R	270R	2k7
3R3	33R	330R	3k3
3R9	39R	390R	3k9
4R7	47R	470R	4k7
5R6	56R	560R	5k6
6R8	68R	680R	6k8
8R2	82R	820R	8k2

10k	100k	1M0	10M
12k	120k	1M2	22M
15k	150k	1M5	
18k	180k	1M8	
22k	220k	2M2	0R1
27k	270k	2M7	R22
33k	330k	3M3	
39k	390k	3M9	
47k	470k	4M7	
56k	560k	5M6	
68k	680k	6M8	
82k	820k	8M2	

NOTES:

The resistors above are "common value" 5% types.

The fourth band is called the "tolerance" band. Gold = 5%

(tolerance band Silver =10% but no modern resistors are 10%!!)

"common resistors" have values 10 ohms to 22M.

RESISTORS LESS THAN 10 OHMS

When the **third** band is gold, it indicates the value of the "colors" must be divided by 10.

Gold = "divide by 10" to get values 1R0 to 8R2

See 1st Column above for examples.

When the **third** band is silver, it indicates the value of the "colors" must be divided by 100.

(Remember: more letters in the word "silver" thus the divisor is "larger.")

Silver = "divide by 100" to get values 0R1 (one tenth of an ohm) to 0R82

e.g: 0R1 = 0.1 ohm 0R22 = point 22 ohms

See 4th Column above for examples.

The letters "R, k and M" take the place of a decimal point. The letter "E" is also used to indicate the word "ohm."

e.g: 1R0 = 1 ohm 2R2 = 2 point 2 ohms 22R = 22 ohms

2k2 = 2,200 ohms 100k = 100,000 ohms

2M2 = 2,200,000 ohms

Common resistors have 4 bands. These are shown above. First two bands indicate the first two digits of the resistance, third band is the multiplier (number of zeros that are to be added to the number derived from first two bands) and fourth represents the tolerance.

Marking the resistance with five bands is used for resistors with tolerance of 2%, 1% and other high-accuracy resistors. First three bands determine the first three digits, fourth is the multiplier and fifth represents the tolerance.

For SMD (Surface Mounted Device) the available space on the resistor is very small. 5% resistors use a 3 digit code, while 1% resistors use a 4 digit code.

Some SMD resistors are made in the shape of small cylinder while the most common type is flat. Cylindrical SMD resistors are marked with six bands - the first five are "read" as with common five-band resistors, while the sixth band determines the Temperature Coefficient (TC), which gives us a value of resistance change upon 1-degree temperature change.

The resistance of flat SMD resistors is marked with digits printed on their upper side. First two digits are the resistance value, while the third digit represents the number of zeros. For example, the printed number 683 stands for 68000Ω , that is 68k.

It is self-obvious that there is mass production of all types of resistors. Most commonly used are the resistors of the E12 series, and have a tolerance value of 5%. Common values for the first two digits are: 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68 and 82.

The E24 series includes all the values above, as well as: 11, 13, 16, 20, 24, 30, 36, 43, 51, 62, 75 and 91. What do these numbers mean? It means that resistors with values for digits "39" are: 0.39Ω , 3.9Ω , 39Ω , 390Ω , $3.9k\Omega$, $39k\Omega$, etc are manufactured. (0R39, 3R9, 39R, 390R, 3k9, 39k)

For some electrical circuits, the resistor tolerance is not important and it is not specified. In that case, resistors with 5% tolerance can be used. However, devices which require resistors to have a certain amount of accuracy, need a specified tolerance.

1.2 Resistor Dissipation

If the flow of current through a resistor increases, it heats up, and if the temperature exceeds a certain critical value, it can be damaged. The wattage rating of a resistor is the power it can dissipate over a long period of time.

Wattage rating is not identified on small resistors. The following diagrams show the size and wattage rating:

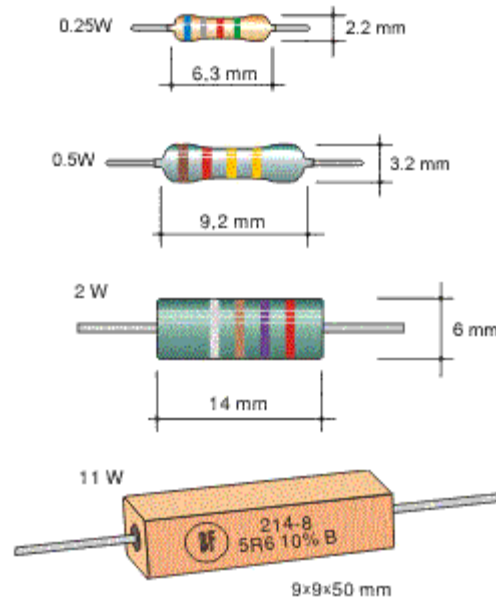


Fig. 1.3: Resistor dimensions

Most commonly used resistors in electronic circuits have a wattage rating of 1/2W or 1/4W. There are smaller resistors (1/8W and 1/16W) and higher (1W, 2W, 5W, etc).

In place of a single resistor with specified dissipation, another one with the same resistance and higher rating may be used, but its larger dimensions increase the space taken on a printed circuit board as well as the added cost.

Power (in watts) can be calculated according to one of the following formulae, where U is the symbol for Voltage across the resistor (and is in Volts), I is the symbol for Current in Amps and R is the resistance in ohms:

$$P = U \cdot I$$

$$P = R \cdot I^2$$

$$P = \frac{U^2}{R}$$

For example, if the voltage across an 820Ω resistor is 12V, the wattage dissipated by the resistors is:

$$P = \frac{U^2}{R} = \frac{12^2}{820} = 0,176 \text{ W} = 176 \text{ mW}$$

A 1/4W resistor can be used.

In many cases, it is not easy to determine the current or voltage across a resistor. In this case the wattage dissipated by the resistor is determined for the "worst" case. We should assume the highest possible voltage across a resistor, i.e. the full voltage of the power supply (battery, etc).

If we mark this voltage as V_B , the highest dissipation is:

$$P = \frac{U_B^2}{R}$$

For example, if $V_B=9V$, the dissipation of a 220Ω resistor is:

$$P = \frac{9^2}{220} = 368 \text{ mW},$$

A 0.5W or higher wattage resistor should be used

1.3 Nonlinear resistors

Resistance values detailed above are a constant and do not change if the voltage or current-flow alters. But there are circuits that require resistors to change value with a change in temperate or light. This function may not be linear, hence the name **NONLINEAR RESISTORS**.

There are several types of nonlinear resistors, but the most commonly used include : *NTC* resistors (figure a) (Negative Temperature Co-efficient) - their resistance lowers with temperature rise. *PTC* resistors (figure b) (Positive Temperature Co-efficient) - their resistance increases with the temperature rise. *LDR* resistors (figure c) (Light Dependent Resistors) - their resistance lowers with the increase in light. *VDR* resistors (Voltage dependent Resistors) - their resistance critically lowers as the voltage exceeds a certain value. Symbols representing these resistors are shown below.

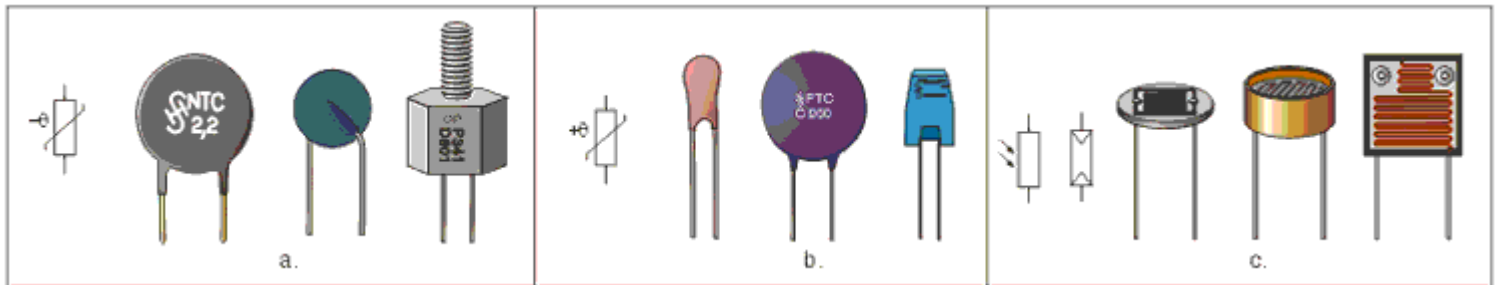
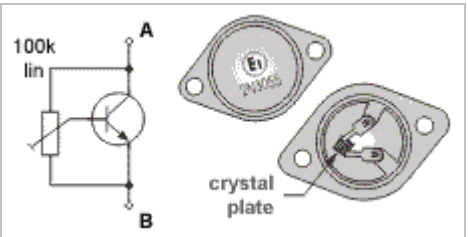


Fig. 1.4: Nonlinear resistors - a. NTC, b. PTC, c. LDR

In amateur conditions where nonlinear resistor may not be available, it can be replaced with other components. For example, *NTC* resistor may be replaced with a transistor with a trimmer potentiometer, for adjusting the required resistance value. Automobile light may play the role of *PTC* resistor, while *LDR* resistor could be replaced with an open transistor. As an example, figure on the right shows the 2N3055, with its upper part removed, so that light may fall upon the crystal inside.



1.4 Practical examples with resistors

Figure 1.5 shows two practical examples with nonlinear and regular resistors as trimmer potentiometers, elements which will be covered in the following chapter.

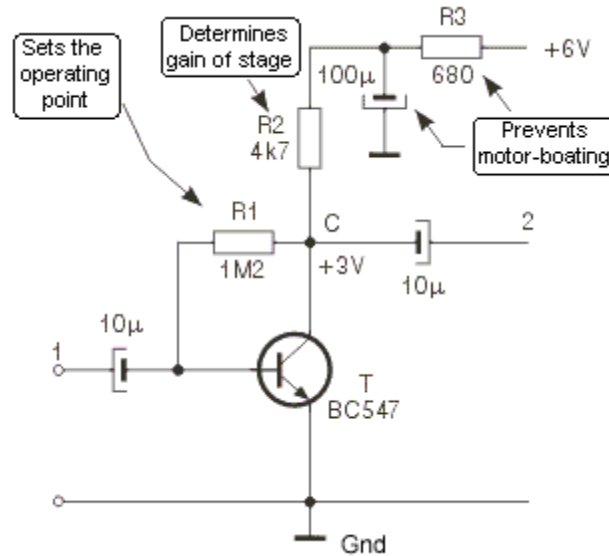


Fig. 1.5a: RC amplifier

Figure 1.5a represents an RC voltage amplifier, that can be used for amplifying low-frequency, low-amplitude audio signals, such as microphone signals. The signal to be amplified is brought between node 1 (amplifier input) and gnd, while the resulting amplified signal appears between node 2 (amplifier output) and gnd. To get the optimal performance (high amplification, low distortion, low noise, etc), it is necessary to "set" the transistor's operating point. Details on the operating point will be provided in chapter 4; for now, let's just say that DC voltage between node C and gnd should be approximately one half of battery (power supply) voltage. Since battery voltage equals 6V, voltage in node C should be set to 3V. Adjustments are made via resistor R1.

Connect a voltmeter between node C and gnd. If voltage exceeds 3V, replace the resistor R1=1.2M Ω with a smaller resistor, say R1=1M Ω . If voltage still exceeds 3V, keep lowering the resistance until it reaches approximately 3V. If the voltage at node C is originally lower than 3V, increase the resistance of R1.

The degree of amplification of the stage depends on R2 resistance: *higher resistance - higher amplification, lower resistance - lower amplification*. If the value of R2 is changed, the voltage at node C should be checked and adjusted (via R1).

Resistor R3 and 100 μ F capacitor form a filter to prevent feedback from occurring. This feedback is called "Motor-boating" as it sounds like the noise from a motor-boat. This noise is only produced when more than one stage is employed.

As more stages are added to a circuit, the chance of feedback, in the form of instability or motor-boating, will occur.

This noise appears at the output of the amplifier, even when no signal is being delivered to the amplifier.

The instability is produced in the following manner:

Even though no signal is being delivered to the input, the output stage produces a very small background noise called "hiss. This comes from current flowing through the transistors and other components.

This puts a very small waveform on the power rails. This waveform is passed to the input of the first transistor and thus we have produced a loop for "noise-generation." The speed with which the signal can pass around the circuit determines the frequency of the instability. By adding a resistor and electrolytic to each stage, a low-frequency filter is produced and this "kills" or reduces the amplitude of the offending signal. The value of R3 can be increased if needed.

Practical examples with resistors will be covered in the following chapters as almost all circuits require resistors.

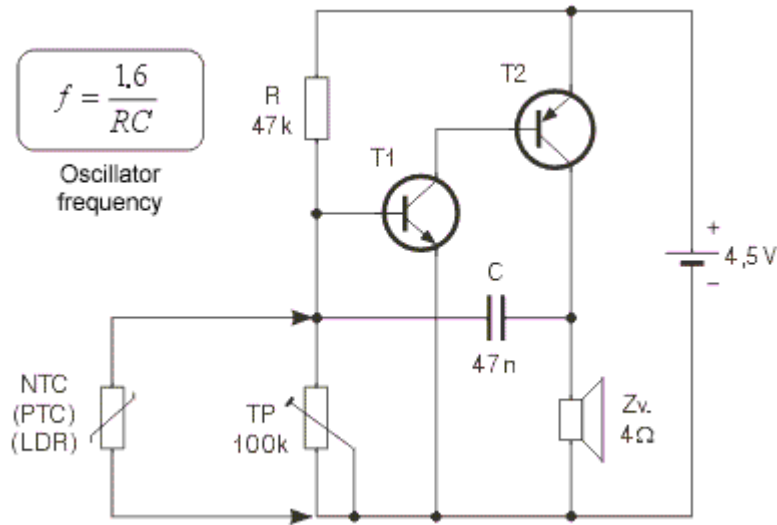


Fig. 1.5b: Sound indicator of changes in temperature or the amount of light

A practical use for nonlinear resistors is illustrated on a simple alarm device shown in figure 1.5b. Without trimmer TP and nonlinear NTC resistor it is an audio oscillator. Frequency of the sound can be calculated according to the following formula:

$$f = \frac{1.6}{RC}$$

In our case, $R=47k\Omega$ and $C=47nF$, and the frequency equals:

$$f = \frac{1.6}{47 \cdot 10^3 \cdot 47 \cdot 10^{-9}} \approx 724 \text{ Hz}.$$

When, according to the figure, trim pot and NTC resistor are added, oscillator frequency increases. If the trim pot is set to minimum resistance, the oscillator stops. At the desired temperature, the resistance of the trim pot should be increased until the oscillator starts working again. For example, if these settings were made at 2°C , the oscillator remains frozen at higher temperatures, as the NTC resistor's resistance is lower than nominal. If the temperature falls the resistance increases and at 2°C the oscillator is activated.

If an NTC resistor is installed in a car, close to the road surface, the oscillator can warn driver if the road is covered with ice. Naturally, the resistor and two copper wires connecting it to the circuit should be protected from dirt and water.

If, instead of an NTC resistor, a PTC resistor is used, the oscillator will be activated when the temperature rises above a certain designated value. For example, a PTC resistor could be used for indicating the state of a refrigerator: set the oscillator to work at temperatures above 6°C via trimmer TP, and the circuit will signal if anything is wrong with the fridge.

Instead of an NTC, we could use an LDR resistor - the oscillator would be blocked as long as a certain amount of light is present. In this way, we could make a simple alarm system for rooms where a light must be always on.

The LDR can be coupled with resistor R. In that case, the oscillator works when the light is present, otherwise it is blocked. This could be an interesting alarm clock for hunters and fishermen who would like to get up at the crack of dawn, but only if the weather is clear. For the desired moment in the early morning, the trim pot should be set to the uppermost position. Then, the resistance should be carefully reduced, until the oscillator starts. During the night the oscillator will be blocked, since there is no light and LDR resistance is very high. As the amount of light increases in the morning, the resistance of the LDR drops and the oscillator is activated when the LDR is illuminated with the required amount of light.

The trim pot from the figure 1.5b is used for fine adjustments. Thus, TP from figure 1.5b can be used for setting the oscillator to activate under different

conditions (higher or lower temperature or amount of light).

1.5 Potentiometers

Potentiometers (also called *pots*) are variable resistors, used as voltage or current regulators in electronic circuits. By means of construction, they can be divided into 2 groups: coated and wire-wound.

With coated potentiometers, (figure 1.6a), insulator body is coated with a resistive material. There is a conductive slider moving across the resistive layer, increasing the resistance between slider and one end of pot, while decreasing the resistance between slider and the other end of pot.

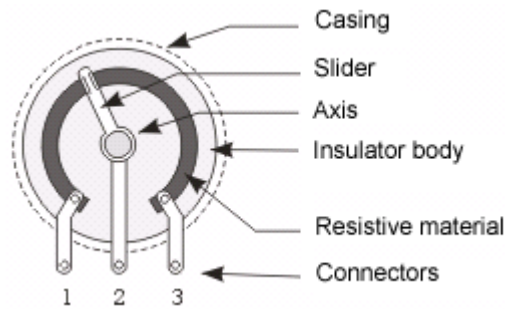


Fig. 1.6a: Coated potentiometer

Wire-wound potentiometers are made of conductor wire coiled around insulator body. There is a slider moving across the wire, increasing the resistance between slider and one end of pot, while decreasing the resistance between slider and the other end of pot.

Coated pots are much more common. With these, resistance can be linear, logarithmic, inverse-logarithmic or other, depending upon the angle or position of the slider. Most common are linear and logarithmic potentiometers, and the most common applications are radio-receivers, audio amplifiers, and similar devices where pots are used for adjusting the volume, tone, balance, etc.

Wire-wound potentiometers are used in devices which require more accuracy in control. They feature higher dissipation than coated pots, and are therefore in high current circuits.

Potentiometer resistance is commonly of E6 series, including the values: 1, 2.2 and 4.7. Standard tolerance values include 30%, 20%, 10% (and 5% for wire-wound pots).

Potentiometers come in many different shapes and sizes, with wattage ranging from 1/4W (coated pots for volume control in amps, etc) to tens of watts (for regulating high currents). Several different pots are shown in the photo 1.6b, along with the symbol for a potentiometer.

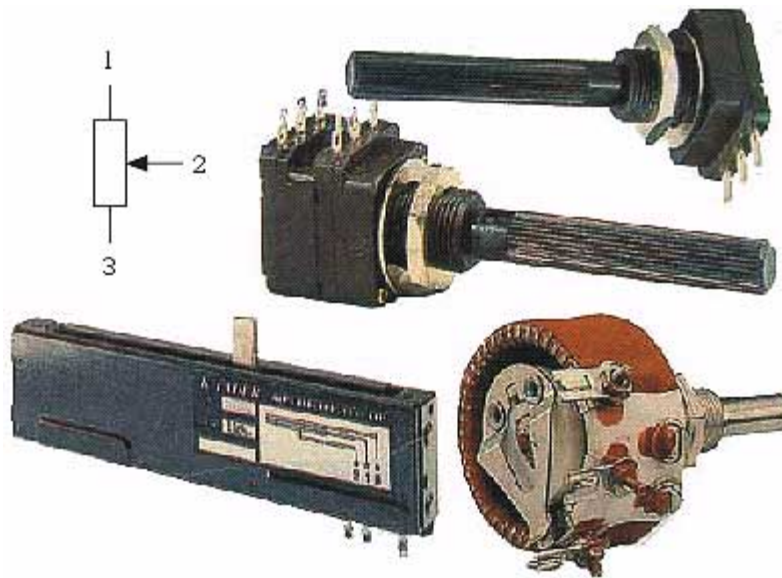


Fig. 1.6b: Potentiometers

The upper model represents a stereo potentiometer. These are actually two pots in one casing, with sliders mounted on shared axis, so they move simultaneously. These are used in stereophonic amps for simultaneous regulation of both left and right channels, etc.

Lower left is the so called slider potentiometer.

Lower right is a wire-wound pot with a wattage of 20W, commonly used as rheostat (for regulating current while charging a battery etc).

For circuits that demand very accurate voltage and current values, *trimmer potentiometers* (or just *trim pots*) are used. These are small potentiometers with a slider that is adjusted via a screwdriver.

Trim pots also come in many different shapes and sizes, with wattage ranging from 0.1W to 0.5W. Image 1.7 shows several different trim pots, along with the symbol.

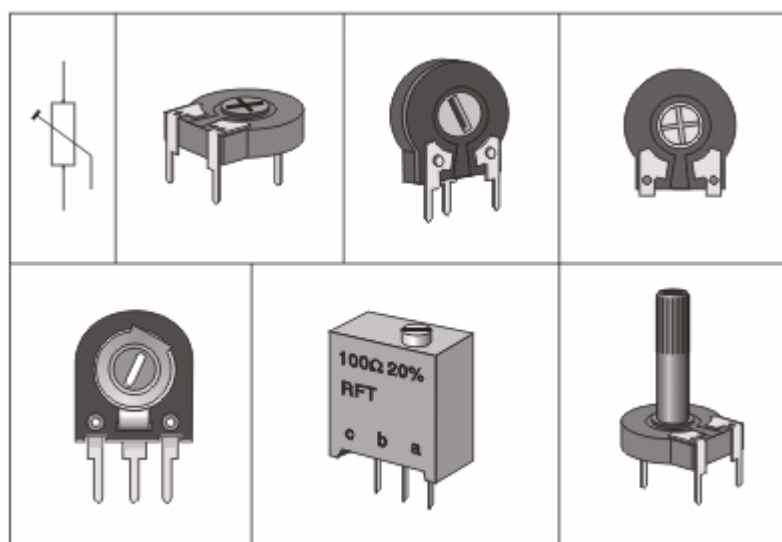


Fig. 1.7: Trim pots

Resistance adjustments are made via a screwdriver. Exception is the trim pot on the lower right, which can be adjusted via a plastic shaft. Particularly fine adjusting can be achieved with the trim pot in the plastic rectangular casing (lower middle). Its slider is moved via a screw, so that several full turns is required to move the slider from one end to the other.

1.6 Practical examples with potentiometers

As previously stated, potentiometers are most commonly used in amps, radio and TV receivers, cassette players and similar devices. They are used for adjusting volume, tone, balance, etc.

As an example, we will analyze the common circuit for tone regulation in an audio amp. It contains two pots and is shown in the figure 1.8a.

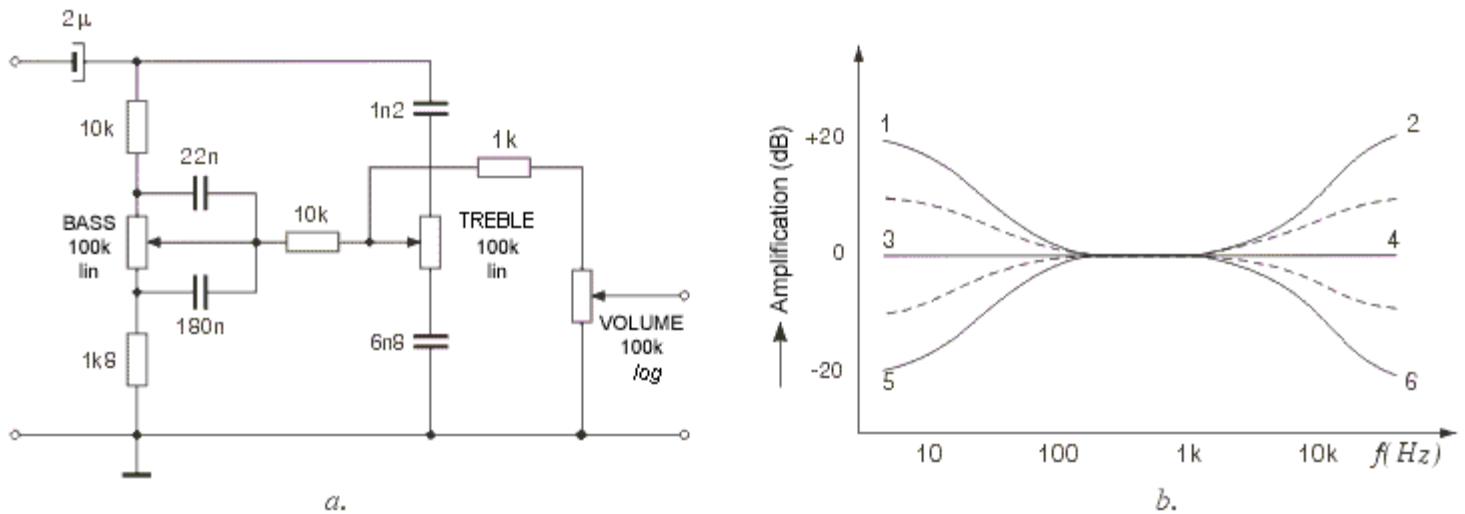


Fig. 1.8 Tone regulation circuit: a. Electrical scheme, b. Function of amplification

Potentiometer marked BASS regulates low frequency amplification. When the slider is in the lowest position, amplification of very low frequency signals (tens of Hz) is about ten times greater than the amplification of mid frequency signals (~kHz). If slider is in the uppermost position, amplification of very low frequency signals is about ten times lower than the amplification of mid frequency signals. Low frequency boost is useful when listening to music with a beat (disco, jazz, R&B...), while Low Frequency amplification should be reduced when listening to speech or classical music.

Similarly, potentiometer marked TREBLE regulates high frequency amplification. High frequency boost is useful when music consists of high-pitched tones such as chimes, while for example High Frequency amplification should be reduced when listening to an old record to reduce the background noise.

Diagram 1.8b shows the function of amplification depending upon the signal frequency. If both sliders are in their uppermost position, the result is shown with curve 1-2. If both are in mid position function is described with line 3-4, and with both sliders in the lowest position, the result is shown with curve 5-6. Setting the pair of sliders to any other possible results in curves between curves 1-2 and 5-6.

Potentiometers BASS and TREBLE are coated by construction and linear by resistance.

The third pot in the diagram is a volume control. It is coated and logarithmic by resistance (hence the mark *log*)

2. Capacitors

Capacitors are common components of electronic circuits, used almost as frequently as resistors. The basic difference between the two is the fact that capacitor resistance (called reactance) depends on the frequency of the signal passing through the item. The symbol for reactance is X_c and it can be calculated using the following formula:

$$X_c = \frac{1}{2\pi fC}$$

f representing the frequency in Hz and C representing the capacitance in Farads.

For example, 5nF-capacitor's reactance at $f=125\text{kHz}$ equals:

$$X_c = \frac{1}{2 \cdot 3,14 \cdot 125\,000 \cdot 5 \cdot 10^{-9}} = 255 \, \Omega,$$

while, at $f=1.25\text{MHz}$, it equals:

$$X_c = \frac{1}{2 \cdot 3,14 \cdot 1\,250\,000 \cdot 5 \cdot 10^{-9}} = 25,5 \, \Omega.$$

A capacitor has an infinitely high reactance for direct current, because $f=0$.

Capacitors are used in circuits for many different purposes. They are common components of filters, oscillators, power supplies, amplifiers, etc.

The basic characteristic of a capacitor is its capacity - the higher the capacity, the higher is the amount of electricity it can hold. Capacity is measured in Farads (F). As one Farad represents fairly high capacity, smaller values such as microfarad (μF), nanofarad (nF) and picofarad (pF) are commonly used. As a reminder, relations between units are:

$$1\text{F}=10^6\mu\text{F}=10^9\text{nF}=10^{12}\text{pF},$$

that is $1\mu\text{F}=1000\text{nF}$ and $1\text{nF}=1000\text{pF}$. It is essential to remember this notation, as same values may be marked differently in some circuits. For example, 1500pF is the same as 1.5nF , 100nF is $0.1\mu\text{F}$.

A simpler notation system is used as with resistors. If the mark on the capacitor is 120 the value is 120pF , 1n2 stands for 1.2nF , n22 stands for 0.22nF , while .1 μ (or .1u) stands for $0.1\mu\text{F}$.

Capacitors come in various shapes and sizes, depending on their capacity, working voltage, type of insulation, temperature coefficient and other factors. All capacitors can be divided into two groups: those with changeable capacity values and those with fixed capacity values. These will be covered in the following chapters.

2.1 Block-capacitors

Capacitors with fixed values (the so called *block-capacitors*) consist of two thin metal plates (these are called "electrodes" or sometimes called the "foil"), separated by a thin insulating material such as plastic. The most commonly used material for the "plates" is aluminum, while the common materials used for insulator include paper, ceramic, mica, etc after which the capacitors get named. A number of different block-capacitors are shown in the photo below. A symbol for a capacitor is in the upper right corner of the image.



Fig. 2.1: Block capacitors

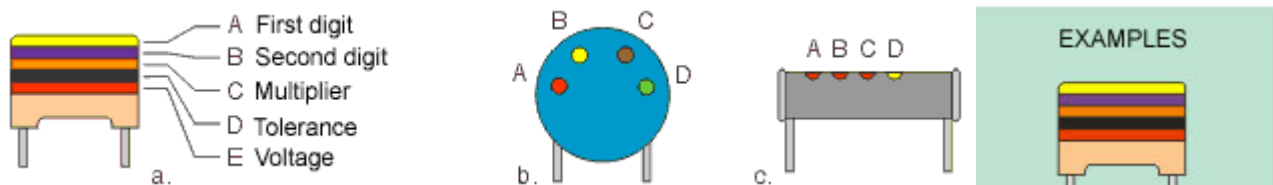
Most of the capacitors, block-capacitors included, are non-polarized components, meaning that their leads are equivalent in respect of the way the capacitor can be placed in a circuit. Electrolytic capacitors represent the exception as their polarity is important. This will be covered in the following chapters.

2.1.1 Marking the block-capacitors

Commonly, capacitors are marked by a set of numbers representing the capacity. Beside this value is another number representing the maximal working voltage, and sometimes tolerance, temperature coefficient and some other values are printed as well. But on the smallest capacitors (such as surface-mount) there are no markings at all and you must not remove them from their protective strips until they are needed. The size of a capacitor is never an indication of its value as the dielectric and the number of layers or "plates" can vary from manufacturer to manufacturer. The value of a capacitor on a circuit diagram, marked as 4n7/40V, means the capacitor is 4,700pF and its maximal working voltage is 40v. Any other 4n7 capacitor with higher maximal working voltage can be used, but they are larger and more expensive.

Sometimes, capacitors are identified with colors, similar to the 4-band system used for resistors (figure 2.2). The first two colors (A and B) represent the first two digits, third color (C) is the multiplier, fourth color (D) is the tolerance, and the fifth color (E) is the working voltage.

With disk-ceramic capacitors (figure 2.2b) and tubular capacitors (figure 2.2c) working voltage is not specified, because these are used in circuits with low DC voltage. If a tubular capacitor has five color bands on it, the first color represents the temperature coefficient, while the other four specify the capacity in the previously described way.



COLOR	DIGIT	MULTIPLIER	TOLERANCE	VOLTAGE
Black	0	x 1 pF	±20%	
Brown	1	x 10 pF	±1%	
Red	2	x 100 pF	±2%	250V
Orange	3	x 1 nF	±2.5%	
Yellow	4	x 10 nF		400V
Green	5	x 100 nF	±5%	
Blue	6	x 1 µF		
Violet	7	x 10 µF		
Grey	8	x 100 µF		
White	9	x 1000 µF	±10%	

Fig. 2.2: Marking the capacity using colors

The figure 2.3 shows how the capacity of miniature tantalum electrolytic capacitors are marked by colors. The first two colors represent the first two digits and have the same values as with resistors. The third color represents the multiplier, to get the capacity expressed in µF. The fourth color represents the maximal working voltage.

A First digit
B Second digit
C Multiplier
D Voltage

470 µF/20V

D
B
A
C

2,2 µF/6,3V

COLOR	DIGIT	MULTIPLIER	VOLTAGE
Black	0	x 1 µF	10V
Brown	1	x 10 µF	
Red	2	x 100 µF	
Orange	3		
Yellow	4		6.3V
Green	5		16V
Blue	6		20V
Violet	7		
Grey	8	x .01 µF	25V
White	9	x .1 µF	3V
Pink			35V

Fig. 2.3: Marking the tantalum electrolytic capacitors

One important note on the working voltage: The voltage across a capacitor must not exceed the maximal working voltage as the capacitor may get destroyed. In the case when the voltage is unknown, the "worst" case should be considered. There is the possibility that, due to malfunction of some other component, the voltage on capacitor equals the power supply voltage. If, for example, the supply is 12V, the maximal working voltage for the capacitor should be higher than 12V.

2.1 Electrolytic capacitors

Electrolytic capacitors represent the special type of capacitors with fixed capacity value. Thanks to special construction, they can have exceptionally high capacity, ranging from one to several thousand μF . They are most frequently used in circuits for filtering, however they also have other purposes.

Electrolytic capacitors are polarized components, meaning they have positive and negative leads, which is very important when connecting it to a circuit. The positive lead or pin has to be connected to the point with a higher positive voltage than the negative lead. If it is connected in reverse the insulating layer inside the capacitor will be "dissolved" and the capacitor will be permanently damaged.

Explosion may also occur if capacitor is connected to voltage that exceeds its working voltage. In order to prevent such instances, one of the capacitor's connectors is very clearly marked with a + or -, while the working voltage is printed on the case.

Several models of electrolytic capacitors, as well as their symbols, are shown on the picture below.

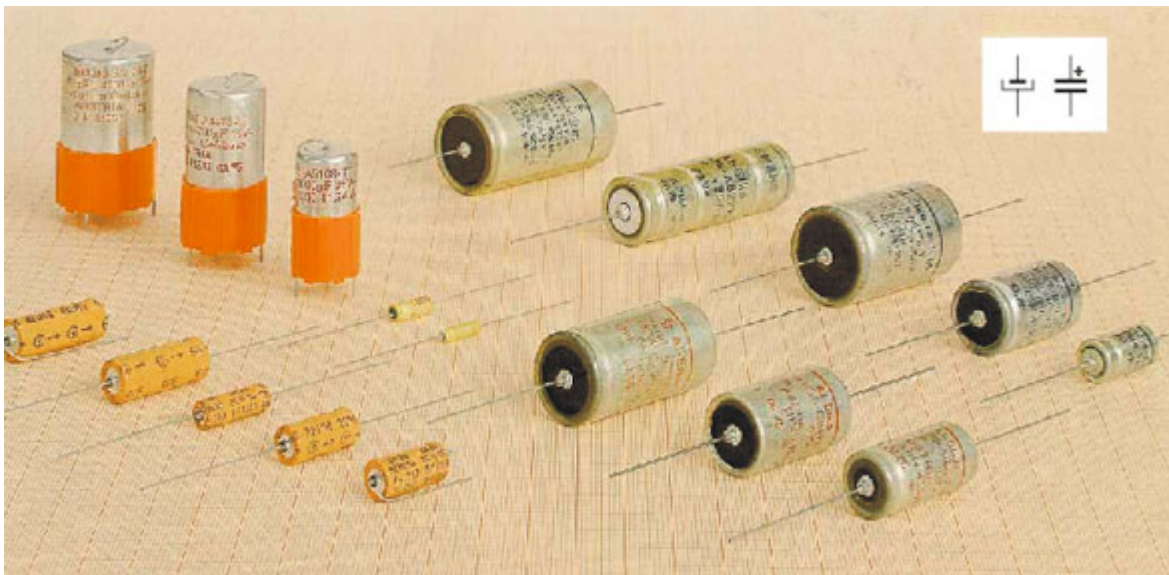


Fig. 2.4: Electrolytic capacitors

Tantalum capacitors represent a special type of electrolytic capacitor. Their parasitic inductance is much lower than standard aluminum electrolytic capacitors so that tantalum capacitors with significantly (even ten times) lower capacity can completely substitute an aluminum electrolytic capacitor.

2.3 Variable capacitors

Variable capacitors are capacitors with variable capacity. Their minimal capacity ranges from 1p and their maximum capacity goes as high as few hundred pF (500pF max). Variable capacitors are manufactured in various shapes and sizes, but common features for them is a set of fixed plates (called the stator) and a set of movable plates. These plates are fitted into each other and can be taken into and out of mesh by rotating a shaft. The insulator (dielectric) between the plates is air or a thin layer of plastic, hence the name variable capacitor. When adjusting these capacitors, it is important that the plates do not touch.

Below are photos of air-dielectric capacitors as well as mylar-insulated variable capacitors (2.5a).

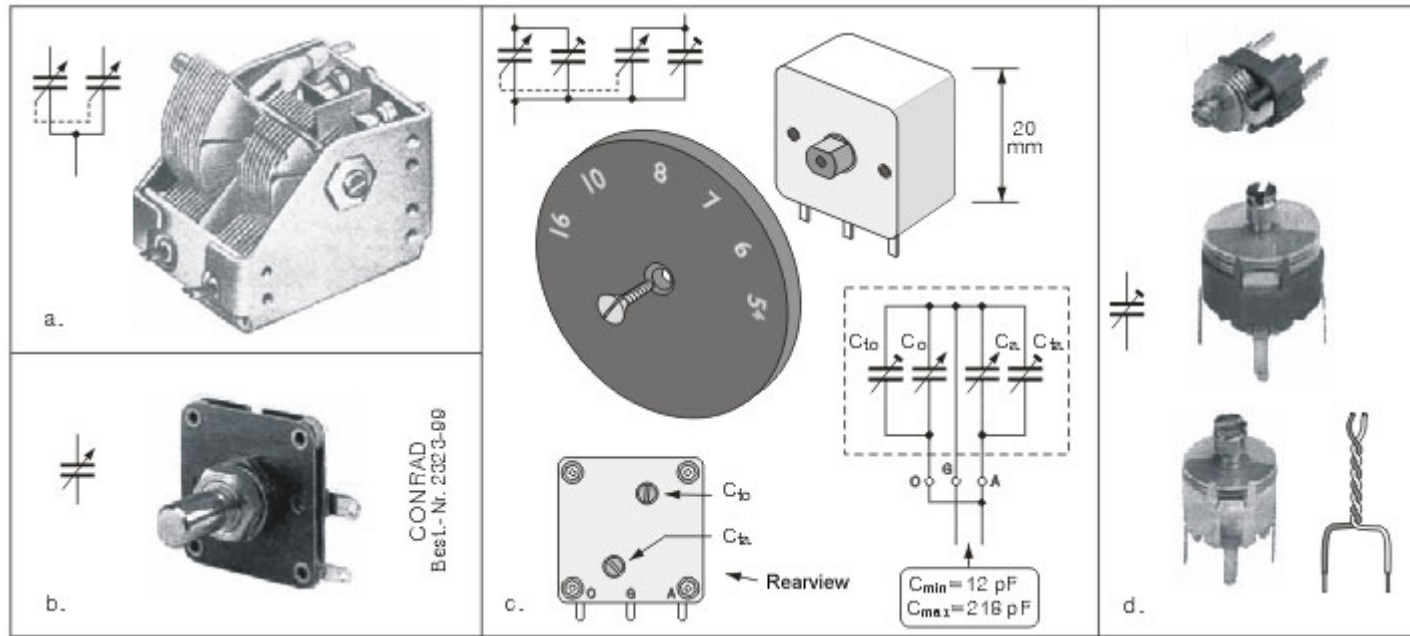


Fig. 2.5: a, b, c. Variable capacitors, d. Trimmer capacitors

The first photo shows a "ganged capacitor" in which two capacitors are rotated at the same time. This type of capacitor is used in radio receivers. The larger is used for the tuning circuit, and the smaller one in the local oscillator. The symbol for these capacitors is also shown in the photo.

Beside capacitors with air dielectric, there are also variable capacitors with solid insulator. With these, thin insulating material such as mylar occupies the space between stator and rotor. These capacitors are much more resistant to mechanical damage. They are shown in figure 2.5b.

The most common devices containing variable capacitors are radio receivers, where these are used for frequency adjustment. Semi-variable or trim capacitors are miniature capacitors, with capacity ranging from several pF to several tens of pFs. These are used for fine tuning radio receivers, radio transmitters, oscillators, etc. Three trimmers, along with their symbol, are shown on the figure 2.5d.

2.4 Practical examples

Several practical examples using capacitors are shown in figure 2.6. A $5\mu\text{F}$ electrolytic capacitor is used for DC blocking. It allows the signal to pass from one stage to the next while prevent the DC on one stage from being passed to the next stage. This occurs because the capacitor acts like a resistor of very low resistance for the signals and as a resistor of high resistance for DC.

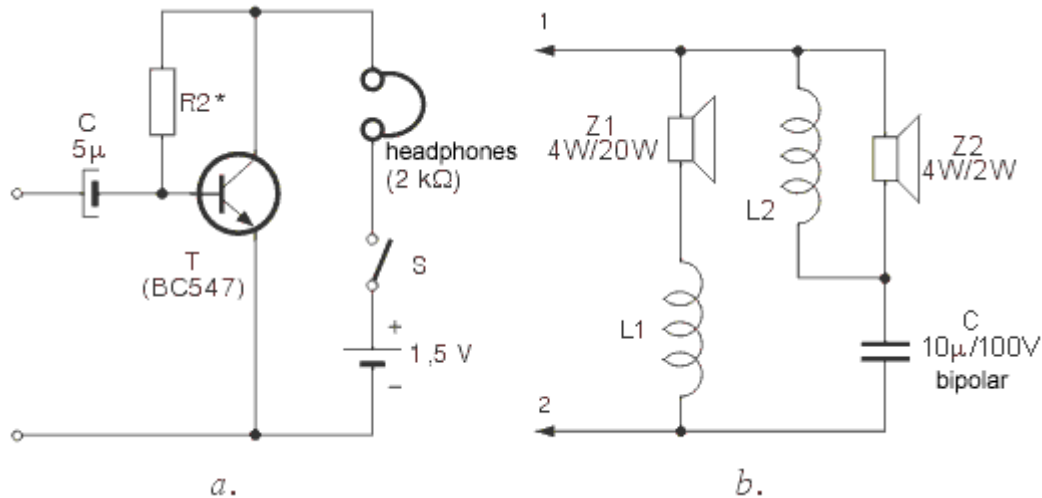


Fig. 2.6: a. Amplifier with headphones, b. Electrical band-switch

The figure 2.6b represents a diagram of a band-switch with two speakers, with Z1 used for reproducing low and mid-frequency signals, and Z2 for high frequency signals. 1 and 2 are connected to the audio amplifier output. Coils L1 and L2 and the capacitor C ensure that low and mid-frequency currents flow to the speaker Z1, while high frequency currents flow to Z2. How this works exactly ? In the case of a high frequency current, it can flow through either Z1 and L1 or Z2 and C. Since the frequency is high, impedance (resistance) of the coils are high, while the capacitor's reactance is low. It is clear that in this case, current will flow through Z2. In similar fashion, in case of low-frequency signals, current will flow through Z1, due to high capacitor reactance and low coil impedance.

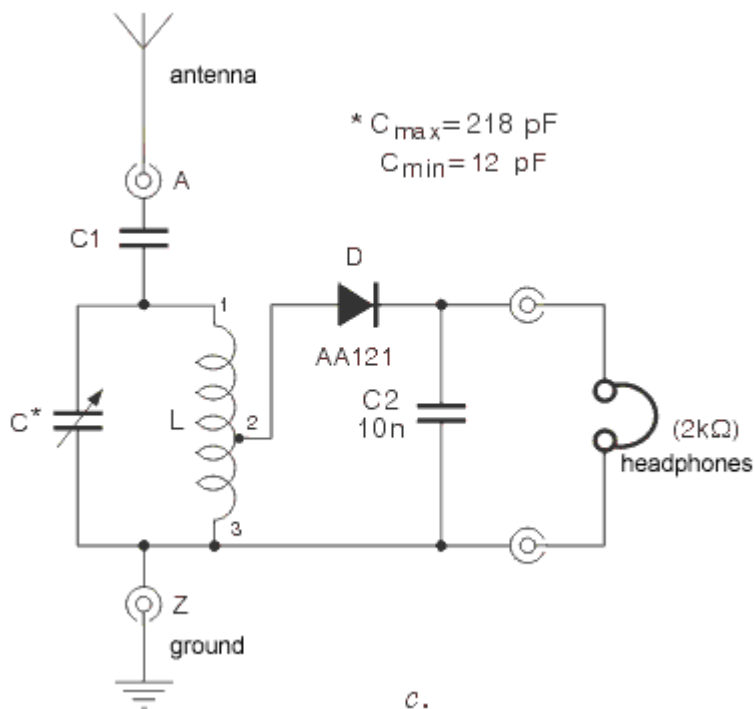


Fig. 2.6: c. Detector radio-receiver

The figure 2.6c represents a circuit diagram for a simple detector radio-receiver (commonly called a "crystal set"), where the variable capacitor C, forming the oscillatory circuit with the coil L, is used for frequency tuning. Turning the capacitor's rotor changes the resonating frequency of the circuit, and when matching a certain radio frequency, the station can be heard.

3. Coils and transformers

3.1 Coils

Coils are not a very common component in electronic circuits, however when they are used, they need to be understood. They are encountered in oscillators, radio-receivers, transmitter and similar devices containing oscillatory circuits. In amateur devices, coils can be made by winding one or more layers of insulated copper wire onto a former such as PVC, cardboard, etc. Factory-made coils come in different shapes and sizes, but the common feature for all is an insulated body with turns of copper wire.

The basic characteristic of every coil is its inductance. Inductance is measured in Henry (H), but more common are millihenry (mH) and microhenry (μH) as one Henry is quite a high inductance value. As a reminder:

$$1\text{H} = 1000\text{mH} = 10^6 \mu\text{H}.$$

Coil inductance is marked by X_L , and can be calculated using the following formula:

$$X_L = 2\pi fL,$$

where f represents the frequency of the voltage in Hz and the L represents the coil inductance in H.

For example, if f equals 684 kHz, while $L=0.6$ mH, coil impedance will be:

$$X_L = 2 \cdot 3,14 \cdot 684000 \cdot 0,6 \cdot 10^{-3} = 2\,577 \, \Omega.$$

The same coil would have three times higher impedance at three times higher frequency. As can be seen from the formula above, coil impedance is in direct proportion to frequency, so that coils, as well as capacitors, are used in circuits for filtering at specified frequencies. Note that coil impedance equals zero for DC ($f=0$).

Several coils are shown on the figures 3.1, 3.2, 3.3, and 3.4.

The simplest coil is a single-layer air core coil. It is made on a cylindrical insulator (PVC, cardboard, etc.), as shown in figure 3.1. In the figure 3.1a, turns have space left between them, while the common practice is to wind the wire with no space between turns. To prevent the coil unwinding, the ends should be put through small holes as shown in the figure.

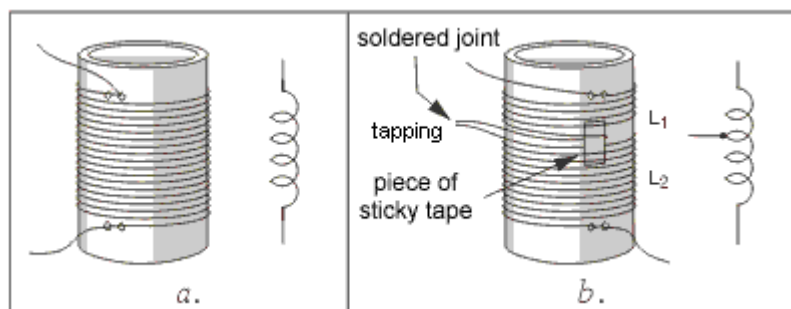


Fig. 3.1: Single-layer coil

Figure 3.1b shows how the coil is made. If the coil needs 120 turns with a tapping on the thirtieth turn, there are two coils L1 with 30 turns and L2 with 90 turns. When the end of the first and the beginning of the second coil are soldered, we get a "tapping."

A multilayered coil is shown in figure 3.2a. The inside of the plastic former has a screw-thread, so that the ferromagnetic core in the shape of a small screw can be inserted. Screwing the core moves it along the axis and into the center of the coil to increase the inductance. In this manner, fine changes to the inductance can be made.

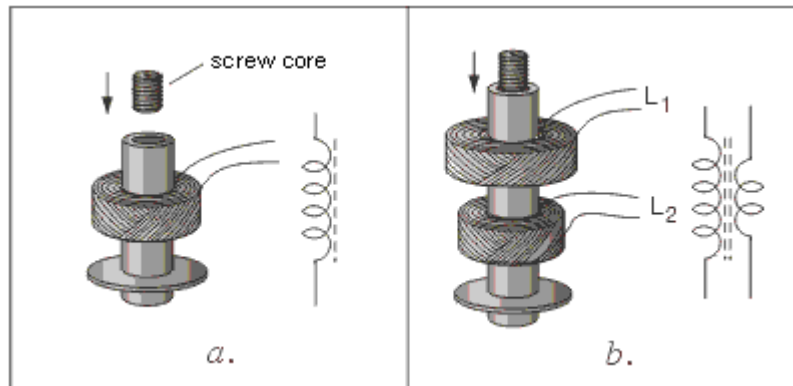


Fig. 3.2: a. Multi-layered coil with core, b. Coupled coils

Figure 3.2b shows a high-frequency transformer. As can be seen, these are two coils are coupled by magnetic induction on a shared body. When the coils are required to have exact inductance values, each coil has a ferromagnetic core that can be adjusted along the coil axis.

At very high frequencies (above 50MHz) coil inductance is small, so coils need only a few turns. These coils are made of thick copper wire (approx. 0.5mm) with no coil body, as shown on the figure 3.3a. Their inductance can be adjusted by physically stretching or squeezing the turns together.

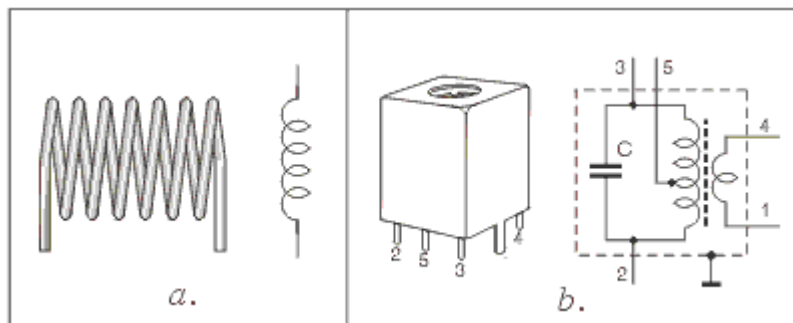


Fig. 3.3: a. High frequency coil, b. Inter-frequency transformer

Figure 3.3b shows a metal casing containing two coils, with the schematic on the right. The parallel connection of the first coil and capacitor C forms an oscillatory circuit. The second coil is used for transferring the signal to the next stage. This is used in radio-receivers and similar devices. The metal casing serves as a screen to prevent external signals affecting the coils. For the casing to be effective, it must be earthed.

Fig 3.4 shows a "pot core" inductor. The core is made in two halves and are glued together. The core is made of ferromagnetic material, commonly called "ferrite." These inductors are used at

frequencies up to 100kHz. Adjustment of the inductance can be made by the brass or steel screw in the centre of the coil.

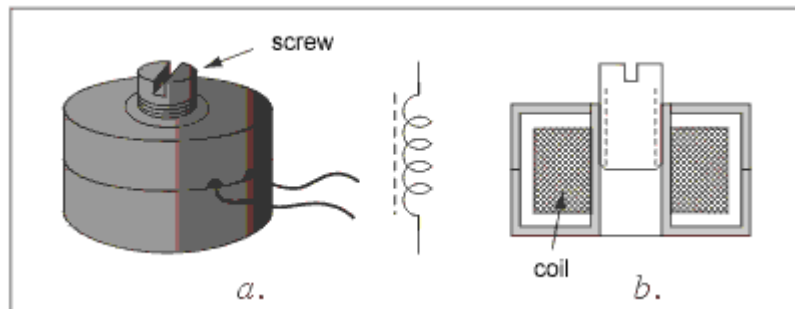


Fig. 3.4: A "pot core" inductor

3.2 Transformers

For electronic devices to function it is necessary to have a DC power supply. Batteries and rechargeable cells can fulfill the role, but a much more efficient way is to use a POWER SUPPLY. The basic component of a power supply is a transformer to transform the 220V "mains" to a lower value, say 12V. A common type of transformer has one primary winding which connects to the 220V and one (or several) secondary windings for the lower voltages. Most commonly, cores are made of E and I laminations, but some are made of ferromagnetic material. There are also iron core transformers used for higher frequencies. Various types of transformers are shown on the picture below.

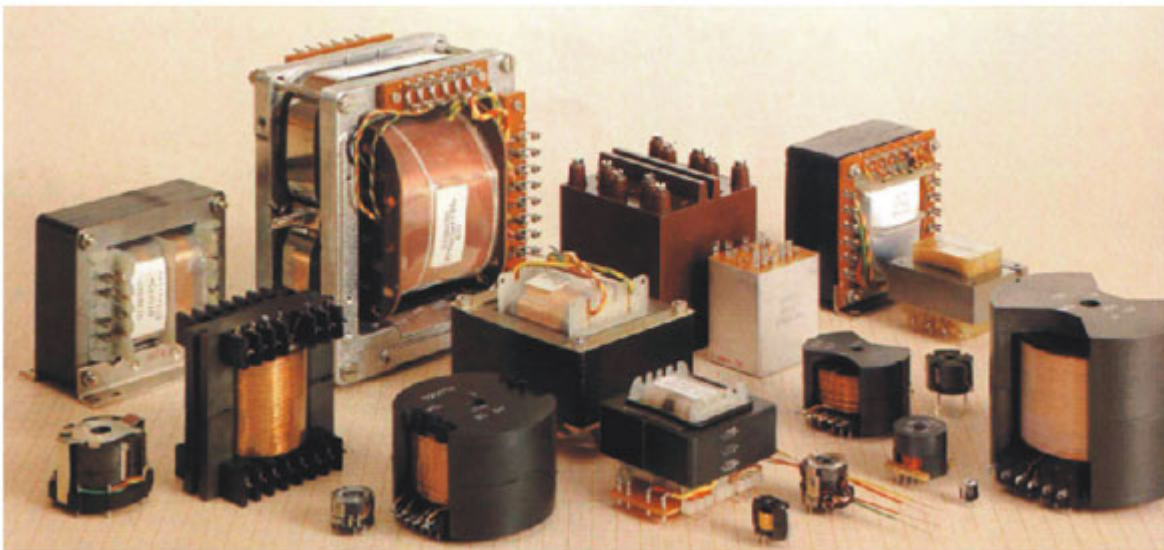


Fig. 3.5: Various types of transformers

Symbols for a transformer are shown on the figure 3.6 Two vertical lines indicate that primary and secondary windings share the same core.

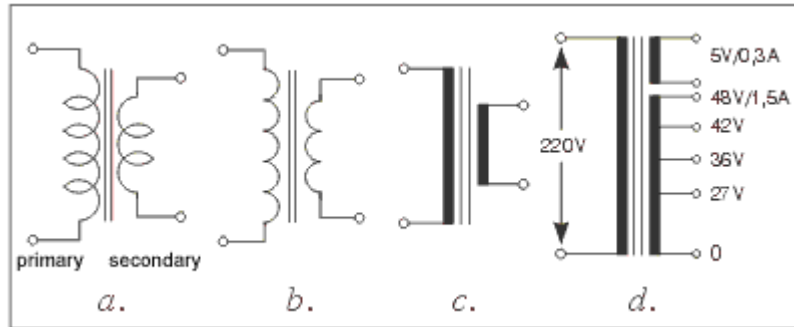


Fig. 3.6: Transformer symbols

With the transformer, manufacturers usually supply a diagram containing information about the primary and secondary windings, the voltages and maximal currents. In the case where the diagram is missing, there is a simple method for determining which winding is the primary and which is the secondary: a primary winding consists of thinner wire and more turns than the secondary. It has a higher resistance - and can be easily be tested by ohmmeter. Figure 3.6d shows the symbol for a transformer with two independent secondary windings, one of them has three tapings, giving a total of 4 different output voltages. The 5v secondary is made of thinner wire with a maximal current of 0.3A, while the other winding is made of thicker wire with a maximal current of 1.5A. Maximum voltage on the larger secondary is 48V, as shown on the figure. Note that voltages other than those marked on the diagram can be produced - for example, a voltage between tapings marked 27V and 36V equals 9V, voltage between tapings marked 27V and 42V equals 15V, etc.

3.2.1 Working principles and basic characteristics

As already stated, transformers consist of two windings, primary and the secondary (figure 3.7). When the voltage U_p is connected to the primary winding (in our case the "mains" is 220V), AC current I_p flows through it. This current creates a magnetic field which passes to the secondary winding via the core of the transformer, inducing voltage U_s (24V in our example). The "load" is connected to the secondary winding, shown in the diagram as R_p (30Ω in our example). A typical load could be an electric bulb working at 24V with a consumption of 19.2W.

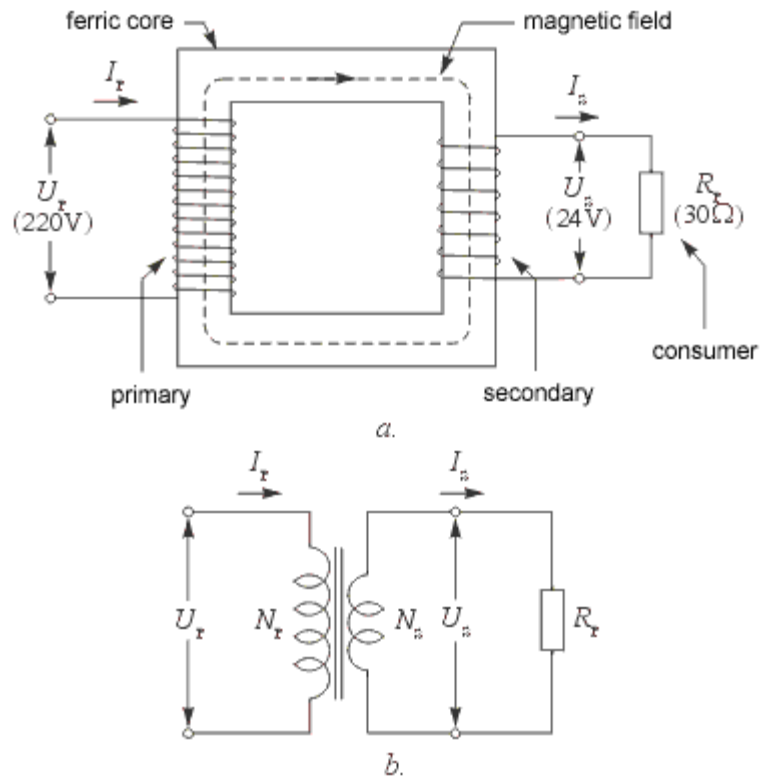


Fig. 3.7: Transformer: a. Working principles, b. Symbol

Transfer of electrical energy from the primary to the secondary is done via a magnetic field (called "flux") and a magnetic circuit called the "core of the transformer." To prevent losses, it is necessary to make sure the whole magnetic field created by the primary passes to the secondary. This is achieved by using an iron core, which has much lower magnetic resistance than air.

Primary voltage is the "mains" voltage. This value can be 220V or 110V, depending on the country. Secondary voltage is usually much lower, such as 6V, 9V, 15V, 24V, etc, but can also be higher than 220V, depending on the transformer's purpose. Relation of the primary and secondary voltage is given with the following formula:

$$\frac{U_s}{U_p} = \frac{N_s}{N_p},$$

where N_s and N_p represent the number of turns on the primary and secondary winding, respectively. For instance, if N_s equals 80 and N_p equals 743, secondary voltage will be:

$$U_s = U_p \cdot \frac{N_s}{N_p} = 220\text{ V} \cdot \frac{80}{734} = 24\text{ V}.$$

Relationship between the primary and secondary current is determined by the following formula:

$$\frac{I_P}{I_S} = \frac{N_S}{N_P}.$$

For instance, if R_p equals 30Ω , then the secondary current equals $I_p = U_p/R_p = 24V/30\Omega = 0.8A$. If N_s equals 80 and N_p equals 743, primary current will be:

$$I_P = I_S \cdot \frac{N_S}{N_P} = 0,8A \cdot \frac{80}{734} = 87mA.$$

Transformer wattage can be calculated by the following formulae:

$$P = U_S \cdot I_S = U_P \cdot I_P.$$

In our example, the power equals:

$$P = U_S \cdot I_S = 24V \cdot 0,8A = 19,2W.$$

Everything up to this point relates to the ideal transformer. Clearly, there is no such thing as perfect, as losses are inevitable. They are present due to the fact that the windings exhibit a certain resistance value, which makes the transformer warm up during operation, and the fact that the magnetic field created by the primary does not entirely pass to the secondary. This is why the output wattage is less than the input wattage. Their ratio is called EFFICIENCY:

$$\eta = \frac{P_S}{P_P}.$$

For transformers delivering hundreds of watts, efficiency is about $\mu=0.85$, meaning that 85% of the electrical energy taken from the mains gets to the consumer, while the 15% is lost due to previously mentioned factors in the form of heat. For example, if power required by the consumer equals $U_p \cdot I_p = 30W$, then the power which the transformer draws from the mains equals:

$$P_P = \frac{P_S}{\eta} = \frac{30W}{0,85} = 35,3W$$

To avoid any confusion here, bear in mind that manufacturers have already taken every measure in minimizing the losses of transformers and other electronic components and that, practically, this is the highest possible efficiency. When acquiring a transformer, you should only worry about the required voltage and the maximal current of the secondary. Dividing the wattage and the secondary voltage gets you the maximal current value for the consumer. Dividing the wattage and the primary voltage gets you the current that the transformer draws from network, which is important to know when buying the fuse. Anyhow, you should be able to calculate any value you might need using the appropriate formulae from above.

3.3 Practical examples with coils and transformers

On the figure 2.6b coils, along with the capacitor, form two filters for conducting the currents to the speakers.

The coil and capacitor C on figure 2.6c form a parallel oscillatory circuit for "amplifying" a particular radio signal, while rejecting all other frequencies.

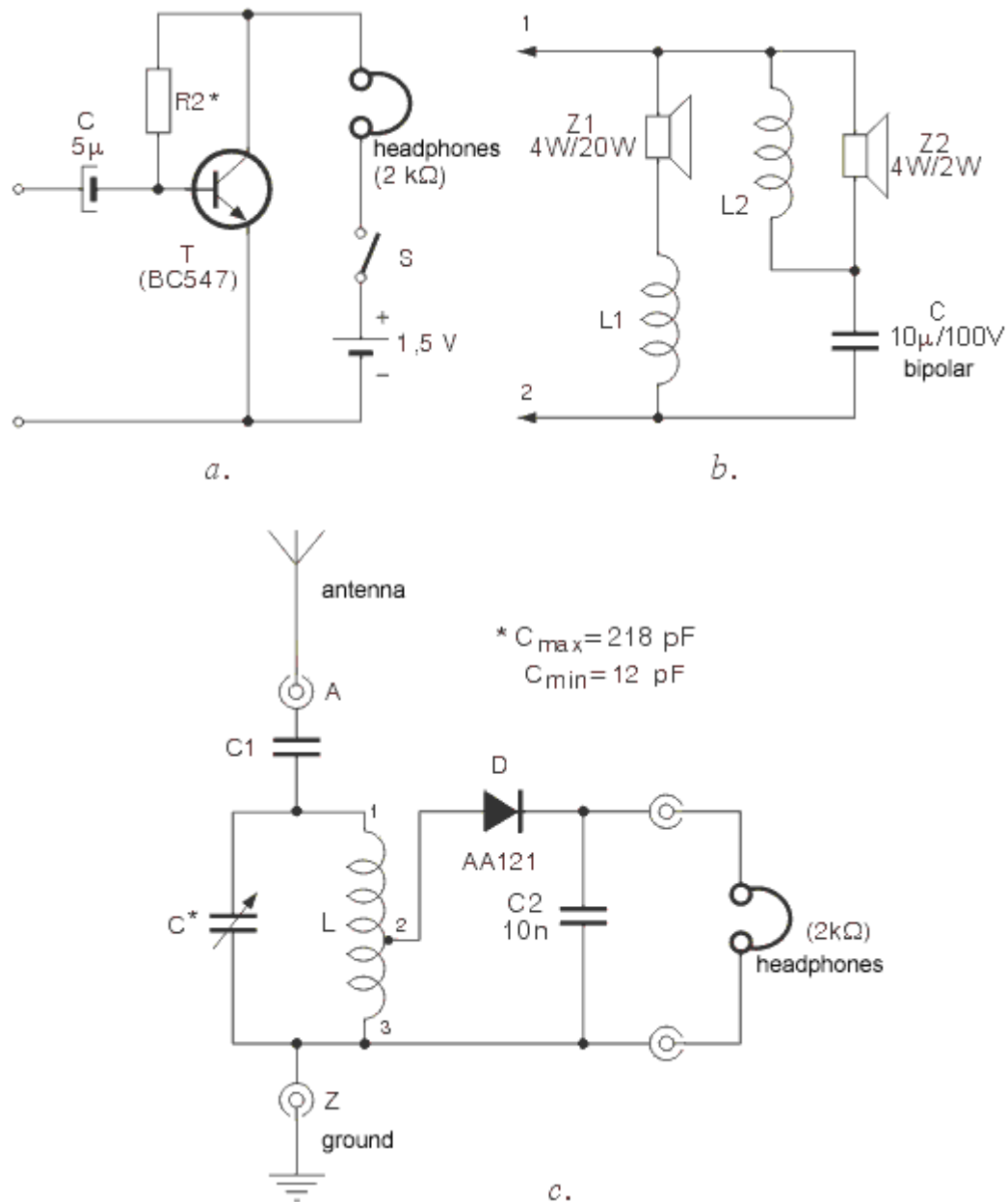


Fig. 2.6: a. Amplifier with headphones, b. Band-switch, c. Detector radio-receiver

The most obvious application for a transformer is in a power supply. A typical transformer is shown in figure 3.8 and is used for converting 220V to 24V.

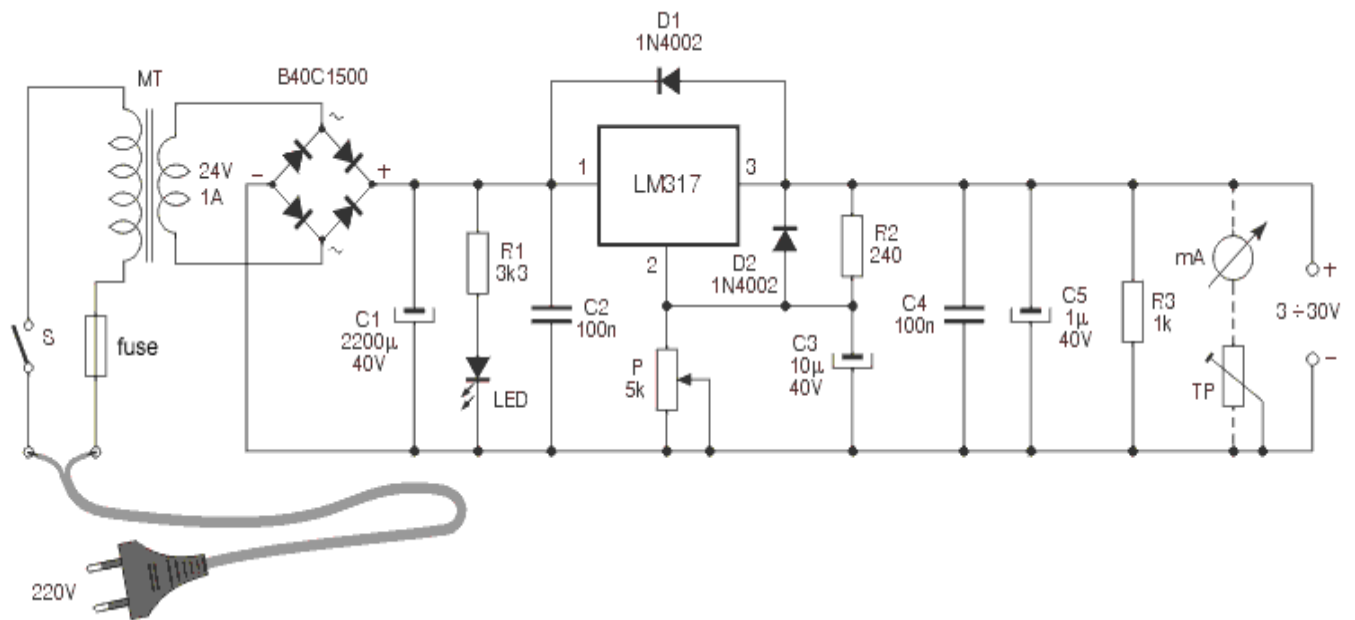


Fig. 3.8: Stabilized converter with circuit LM317

Output DC voltage can be adjusted via a linear potentiometer P, in 3~30V range.

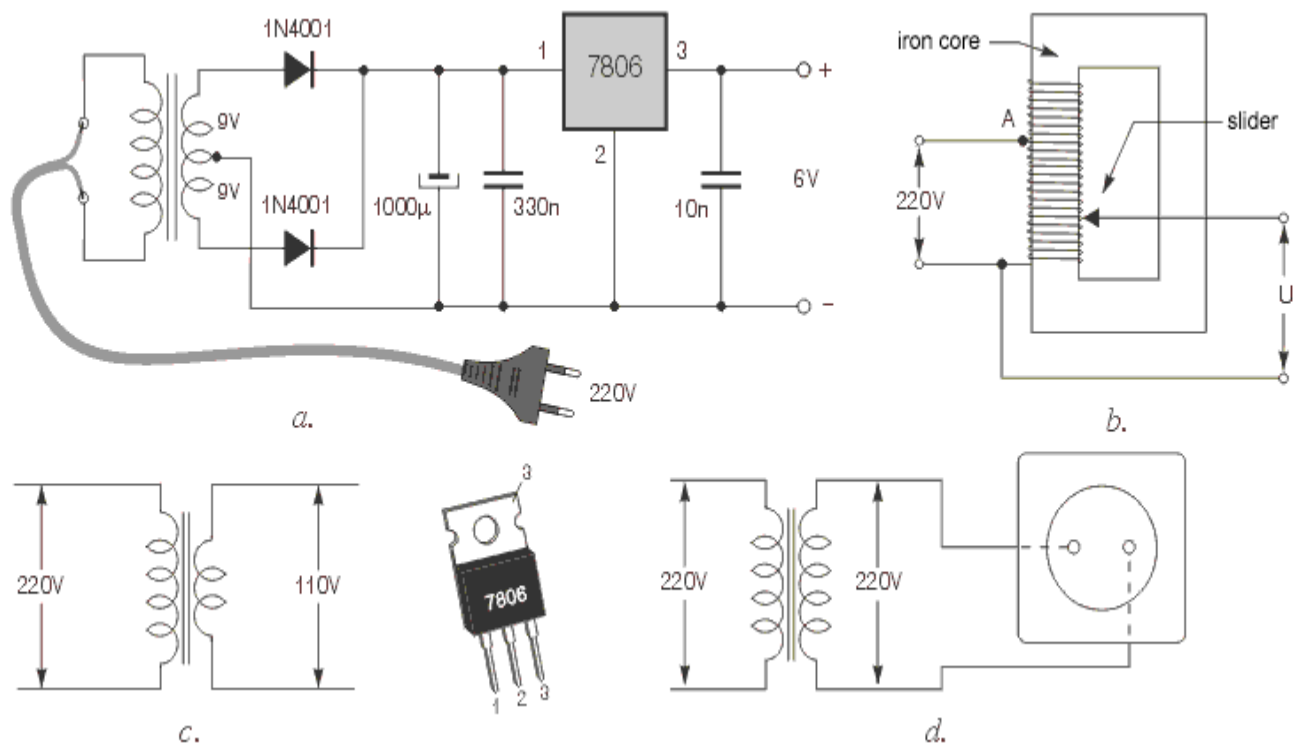


Fig. 3.9: a. Stabilized converter with regulator 7806, b. auto-transformer, c. transformer for devices working at 110V, d. isolating transformer

Figure 3.9a shows a simple power supply, using a transformer with a centre-tap on the secondary winding. This makes possible the use two diodes instead of the bridge in figure 3.8.

Special types of transformers, mainly used in laboratories, are auto-transformers. The diagram for an auto-transformer is shown in figure 3.9b. It features only one winding, wound on an iron core. Voltage is taken from the transformer via a slider. When the slider is in its lowest position, voltage equals zero. Moving the slider upwards increases the voltage U , to 220V. Further moving the slider increases the voltage U above 220V.

The transformer in figure 3.9c converts 220v to 110v and is used for supplying devices designed to work on 110V.

As a final example, figure 3.9d represents an isolating transformer. This transformer features the same number of turns on primary and secondary windings. Secondary voltage is the same as the primary, 220V, but is completely isolated from the "mains," minimizing the risks of electrical shock. As a result, a person can stand on a wet floor and touch any part of the secondary without risk, which is not the case with the normal power outlet.

4. Transistors

Transistors are active components and are found everywhere in electronic circuits. They are used as amplifiers and switching devices. As amplifiers, they are used in high and low frequency stages, oscillators, modulators, detectors and in any circuit needing to perform a function. In digital circuits they are used as switches.

There is a large number of manufacturers around the world who produce semiconductors (transistors are members of this family of components), so there are literally thousands of different types. There are low, medium and high power transistors, for working with high and low frequencies, for working with very high current and/or high voltages. Several different transistors are shown on 4.1.

The most common type of transistor is called bipolar and these are divided into NPN and PNP types.

Their construction-material is most commonly silicon (their marking has the letter B) or germanium (their marking has the letter A). Original transistor were made from germanium, but they were very temperature-sensitive. Silicon transistors are much more temperature-tolerant and much cheaper to manufacture.

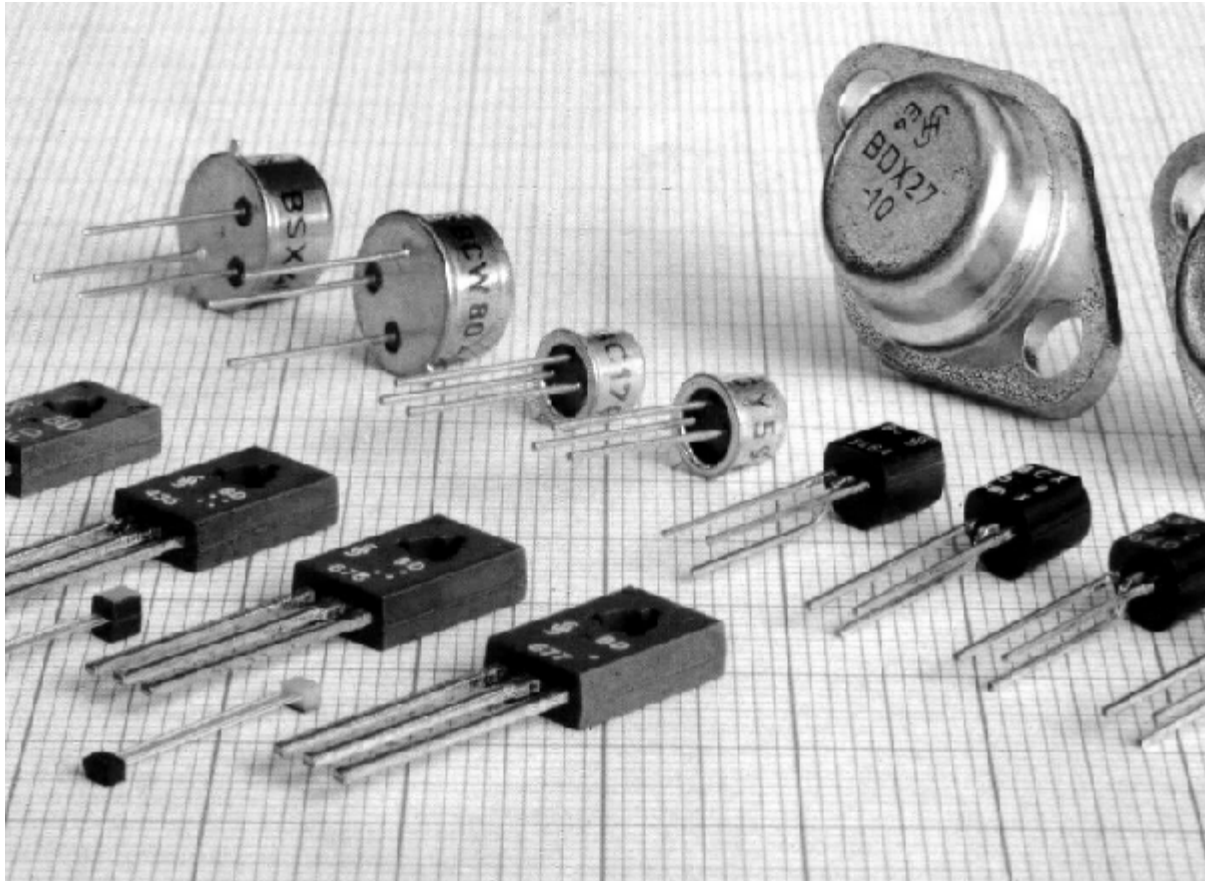


Fig. 4.1: Different transistors

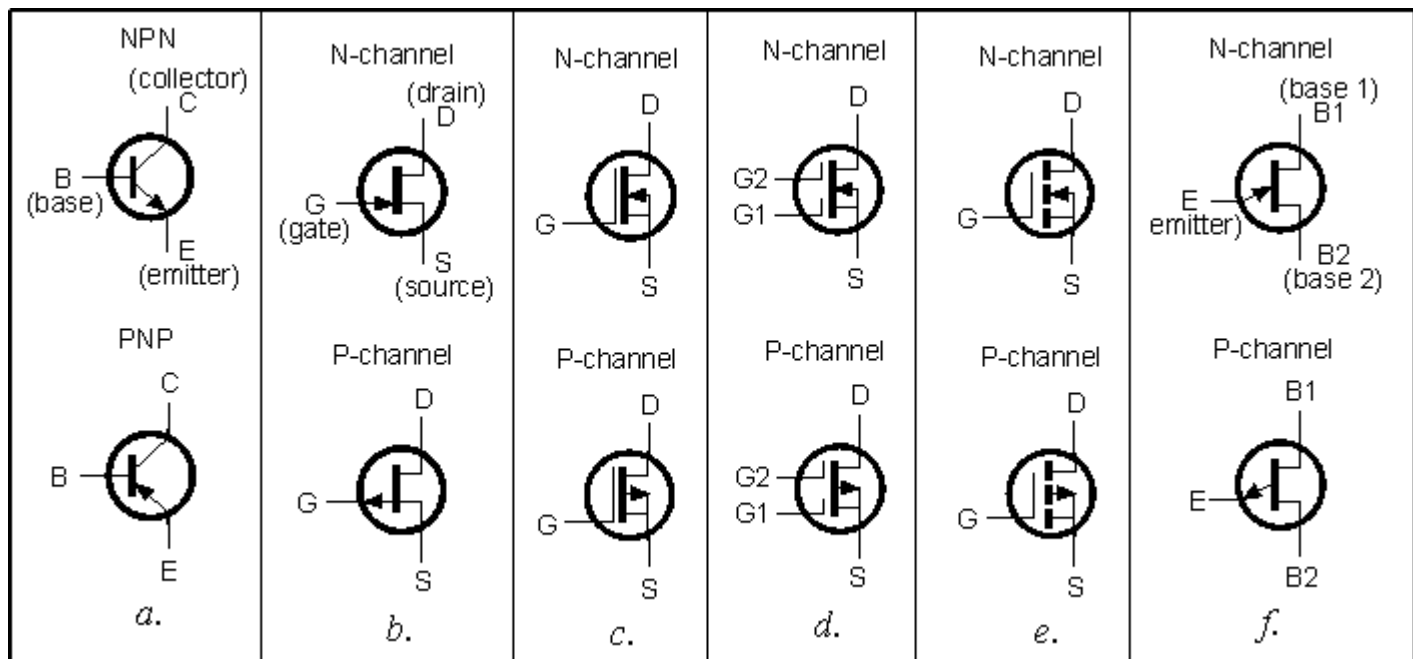


Fig. 4.2: Transistor symbols: a - bipolar, b - FET, c - MOSFET, d - dual gate MOSFET, e - inductive channel MOSFET, f - single connection transistor

The second letter in transistor's marking describes its primary use:

C - low and medium power LF transistor,

D - high power LF transistor,

F - low power HF transistor,

G - other transistors,

L - high power HF transistors,

P - photo transistor,

S - switch transistor,

U - high voltage transistor.

Here are few examples:

AC540 - germanium core, LF, low power,

AF125 - germanium core, HF, low power,

BC107 - silicon, LF, low power (0.3W),

BD675 - silicon, LF, high power (40W),

BF199 - silicon, HF (to 550 MHz),

BU208 - silicon (for voltages up to 700V),

BSY54 - silicon, switching transistor.

There is a possibility of a third letter (R and Q - microwave transistors, or X - switch transistor), but these letters vary from manufacturer to manufacturer.

The number following the letter is of no importance to users.

American transistor manufacturers have different marks, with a 2N prefix followed by a number (2N3055, for example). This mark is similar to diode marks, which have a 1N prefix (e.g. 1N4004).

Japanese bipolar transistor are prefixed with a: 2SA, 2SB, 2SC or 2SD, and FET-s with 3S:

2SA - PNP, HF transistors,

2SB - PNP, LF transistors,

2SC - NPN, HF transistors,

2SD - NPN, HF transistors.

Several different transistors are shown in photo 4.1, and symbols for schematics are on 4.2. Low power transistors are housed in a small plastic or metallic cases of various shapes. Bipolar transistors have three leads: for base (B), emitter (E), and for collector (C). Sometimes, HF transistors have another lead which is connected to the metal housing. This lead is connected to the ground of the circuit, to protect the transistor from possible external electrical interference. Four leads emerge from some other types, such as two-gate FETs. High power transistors are different from low-to-medium power, both in size and in shape.

It is important to have the manufacturer's catalog or a datasheet to know which lead is connected to what part of the transistor. These documents hold the information about the component's correct use (maximum current rating, power, amplification, etc.) as well as a diagram of the pinout. Placement of leads and different housing types for some commonly used transistors are in diagram 4.3.

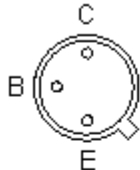
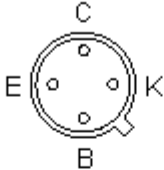
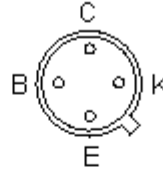
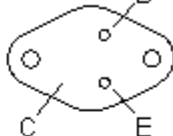
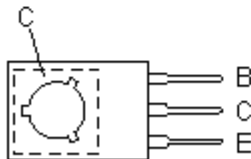
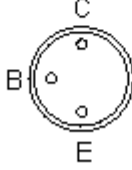
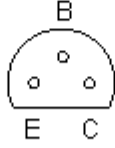

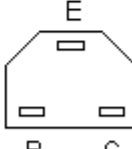
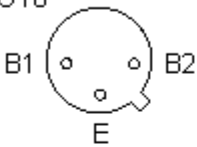
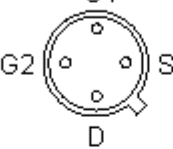

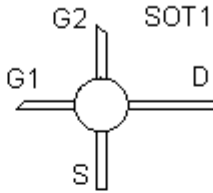
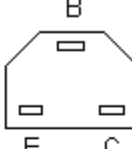
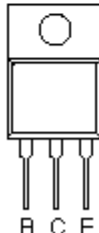
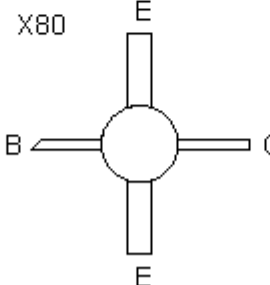
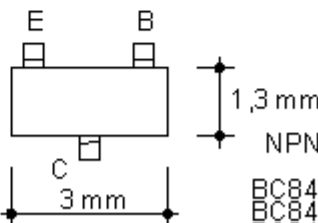
<p>Package TO5, TO18</p>  <p>NPN PNP</p> <p>BC107 BC177 BC108 BC178 BC109 BC179 BFX84 BC186 BFY50 BC187 2N706 BFX88 2N2369 BCY71 BC286 BC287 2N2904</p>	<p>TO72</p> <div><p>NPN PNP</p><p>BF180 AF139 BF181 AF178 BF182 AF179 BF183 AF180 BF200 AF181</p></div> <div><p>NPN PNP</p><p>BF115 AF124 BF167 AF125 BF173 AF126 BF184 AF127 BF185</p></div>		<p>TO3 and similar</p>  <p>NPN PNP</p> <p>2N3055 PNP305 BDY20 BDX18 BD121 OC26 BD123 AD149 AD161 AD162</p>	
<p>TO126</p>  <p>NPN PNP</p> <p>BD135 BD136 BD131 BD132 BD437 BD438 BUP41</p>	<p>TO-1</p>  <p>NPN PNP</p> <p>AC176 AC128 AC187 AC188</p>	<p>X-55</p>  <p>NPN PNP</p> <p>BC182 BC212 BC183 BC213 BC184 BC214 2N3707 2N3702 2N3710 2N3703</p>	<p>TO92</p>  <p>NPN PNP</p> <p>BC183L BC213L BC237B BC557 BC547 BC307B BC548 2N4402 BC546 2N3705 2N3903</p>	<p>SOT25</p>  <p>NPN</p> <p>BF194 BF195 BF196 BF197</p>
<p>TO18</p>  <p>Unijunction transistor</p> <p>2N2646 2N4870 2N2647 2N4871</p>	<p>G1</p>  <p>3N140 3N141 40673</p>	 <p>BF256 2N3819 (connection FET)</p>	<p>G2 SOT103</p>  <p>NPN PNP</p> <p>BF960 BF981 BF961 3SK81</p>	 <p>NPN PNP</p> <p>BC157 BC147 BC158 BC148 BC159 BC149 BCX35 BCX31</p>
<p>TO220</p>  <p>NPN PNP</p> <p>BD539 BD540 BD743 BD744 TIP29C TIP30C BU407 BD244C BUP30 BD240C 2N6099 BD242C BD243C D44C10 BD241C</p>	<p>X80</p>  <p>BFR14 BFR49</p>	<p>SMD SOT23</p>  <p>NPN PNP</p> <p>BC846B BC856B BC847B BC857B BC848B BC858B BC849B BC859B</p>		

Fig. 4.3: Pinouts of some common packages

It might be useful to remember the pinout for TO-1, TO-5, TO-18 and TO-72 packages and compare them with the drawing 4.2 (a). These transistors are the ones you will come across frequently in everyday work.

The TO-3 package, which is used to house high-power transistors, has only two pins, one for base, and one for emitter. The collector is connected to the package, and this is connected to the rest of the circuit via one of the screws which fasten the transistor to the heat-sink.

Transistors used with very high frequencies (like BFR14) have pins shaped differently. One of the breakthroughs in the field of electronic components was the invention of SMD (surface mount devices) circuits. This technology allowed manufacturers to achieve tiny components with the same properties as their larger counterparts, and therefore reduce the size and cost of the design. One of the SMD housings is the SOT23 package. There is, however, a trade-off to this, SMD components are difficult to solder to the PC board and they usually need special soldering equipment.

As we said, there are literally thousands of different transistors, many of them have similar characteristics, which makes it possible to replace a faulty transistor with a different one. The characteristics and similarities can be found in comparison charts. If you do not have one these charts, you can try some of the transistors you already have. If the circuit continues to operate correctly, everything is ok. You can only replace an NPN transistor with an NPN transistor. The same goes if the transistor is PNP or a FET. It is also necessary to make sure the pinout is correct, before you solder it in place and power up the project.

As a helpful guide, there is a chart in this chapter which shows a list of replacements for some frequently used transistors.

4.1 The working principle of a transistor

Transistors are used in analog circuits to amplify a signal. They are also used in power supplies as a regulator and you will also find them used as a switch in digital circuits.

The best way to explore the basics of transistors is by experimenting. A simple circuit is shown below. It uses a power transistor to illuminate a globe. You will also need a battery, a small light bulb (taken from a flashlight) with properties near 4.5V/0.3A, a linear potentiometer (5k) and a 470 ohm resistor. These components should be connected as shown in figure 4.4a.

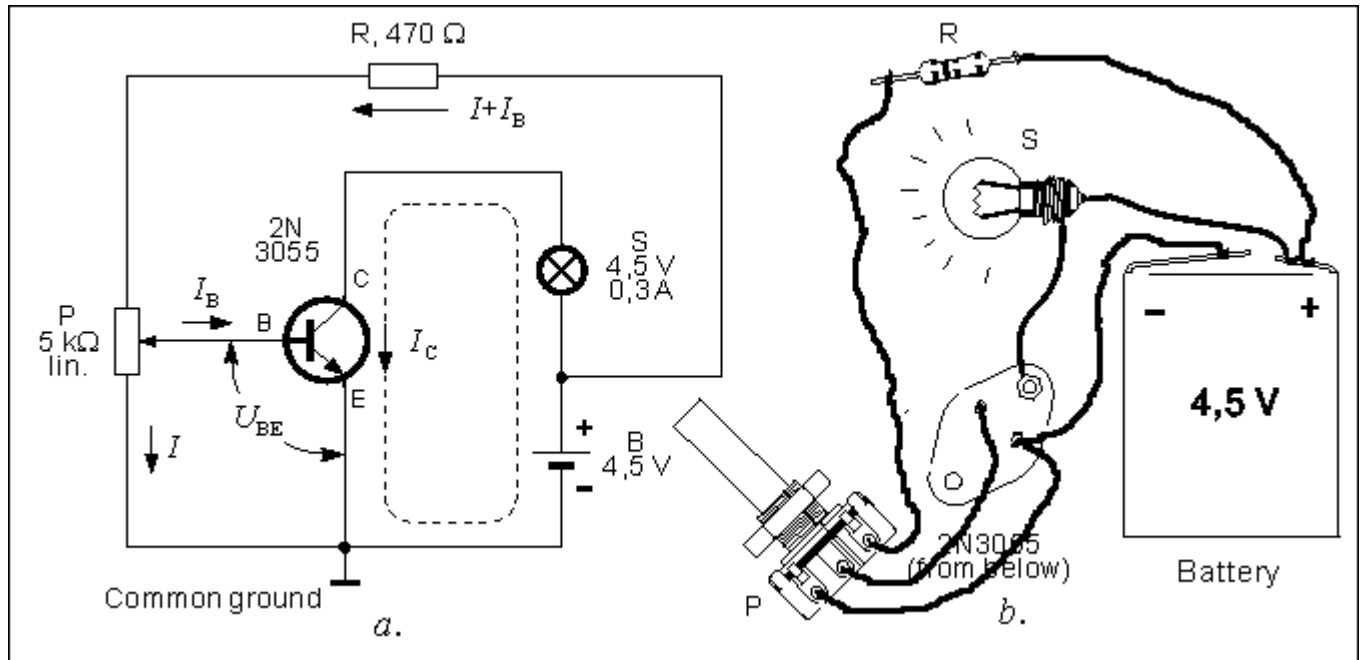


Fig. 4.4: Working principle of a transistor: potentiometer moves toward its upper position - voltage on the base increases - current through the base increases - current through the collector increases - the brightness of the globe increases.

Resistor (R) isn't really necessary, but if you don't use it, you mustn't turn the potentiometer (pot) to its high position, because that would destroy the transistor - this is because the DC voltage U_{BE} (voltage between the base and the emitter), should not be higher than 0.6V, for silicon transistors.

Turn the potentiometer to its lowest position. This brings the voltage on the base (or more correctly between the base and ground) to zero volts ($U_{BE} = 0$). The bulb doesn't light, which means there is no current passing through the transistor.

As we already mentioned, the potentiometers lowest position means that U_{BE} is equal to zero. When we turn the knob from its lowest position U_{BE} gradually increases. When U_{BE} reaches 0.6v, current starts to enter the transistor and the globe starts to glow. As the pot is turned further, the voltage on the base remains at 0.6v but the current increases and this increases the current through the collector-emitter circuit. If the pot is turned fully, the base voltage will increase slightly to about 0.75v but the current will increase significantly and the globe will glow brightly.

If we connected an ammeter between the collector and the bulb (to measure I_C), another ammeter between the pot and the base (for measuring I_B), and a voltmeter between the ground and the base and repeat the whole experiment, we will find some interesting data. When the pot is in its low position U_{BE} is equal to 0V, as well as currents I_C and I_B . When the pot is turned, these values start to rise until the bulb starts to glow when they are: $U_{BE} = 0.6V$, $I_B = 0.8mA$ and $I_C = 36 mA$ (if your values differ from these values, it is because the 2N3055 the writer used

doesn't have the same specifications as the one you use, which is common when working with transistors).

The end result we get from this experiment is that when the current on the base is changed, current on the collector is changed as well.

Let's look at another experiment which will broaden our knowledge of the transistor. It requires a BC107 transistor (or any similar low power transistor), supply source (same as in previous experiment), 1M resistor, headphones and an electrolytic capacitor whose value may range between 10 μ to 100 μ F with any operating voltage.

A simple low frequency amplifier can be built from these components as shown in diagram 4.5.

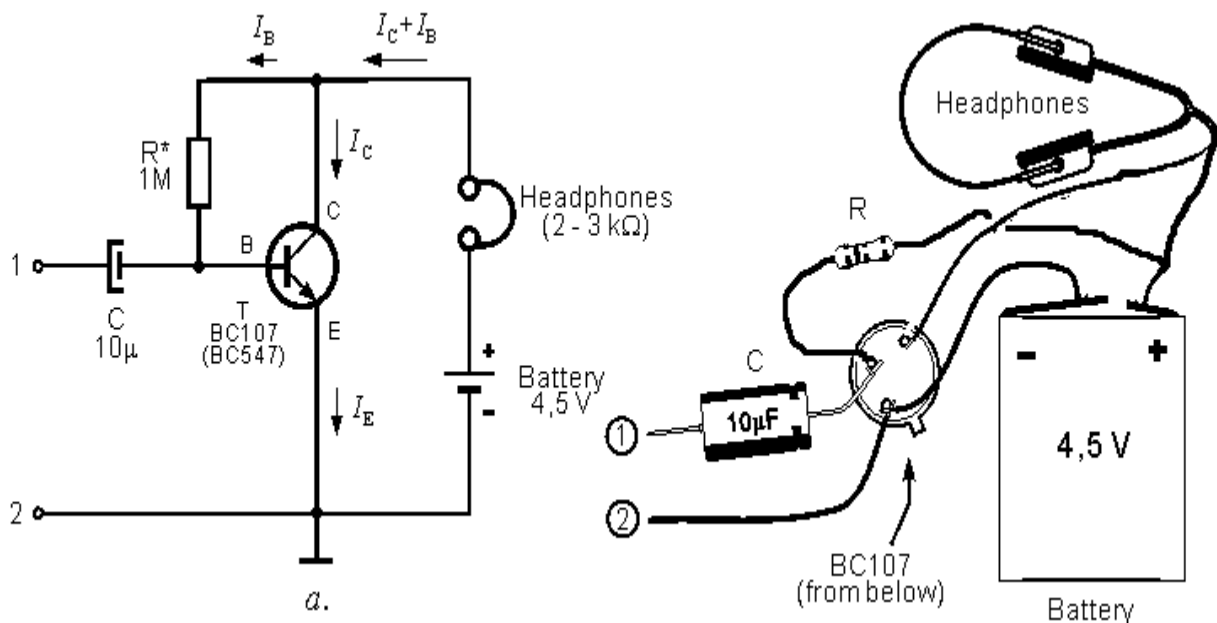


Fig. 4.5: A simple transistor amplifier

It should be noted that the schematic 4.5a is similar to the one on 4.4a. The main difference is that the collector is connected to headphones. The "turn-on" resistor - the resistor on the base, is 1M. When there is no resistor, there is no current flow I_B , and no I_C current. When the resistor is connected to the circuit, base voltage is equal to 0.6V, and the base current $I_B = 4\mu A$. The transistor has a gain of 250 and this means the collector current will be 1 mA. Since both of these currents enter the transistor, it is obvious that the emitter current is equal to $I_E = I_C + I_B$. And since the base current is in most cases insignificant compared to the collector current, it is considered that:

$$I_C = I_E.$$

The relationship between the current flowing through the collector and the current flowing through the base is called the transistor's current amplification coefficient, and is marked as h_{FE} . In our example, this coefficient is equal to:

$$h_{FE} = \frac{I_C}{I_B} = \frac{1mA}{4\mu A} = \frac{1 \cdot 10^{-3} A}{4 \cdot 10^{-6} A} = 250.$$

Put the headphones on and place a fingertip on point 1. You will hear a noise. Your body picks up the 50Hz AC "mains" voltage. The noise heard from the headphones is that voltage, only amplified by the transistor. Let's explain this circuit a bit more. AC voltage with frequency 50Hz is connected to transistor's base via the capacitor C. Voltage on the base is now equal to the sum of a DC voltage (0.6 approx.) via resistor R, and AC voltage "from" the finger. This means that this base voltage is higher than 0.6V, fifty times per second, and fifty times slightly lower than that. Because of this, current on the collector is higher than 1mA fifty times per second, and fifty times lower. This variable current is used to shift the membrane of the speakerphones forward fifty times per second and fifty times backwards, meaning that we can hear the 50Hz tone on the output.

Listening to a 50Hz noise is not very interesting, so you could connect to points 1 and 2 some low frequency signal source (CD player or a microphone).

There are literally thousands of different circuits using a transistor as an active, amplifying device. And all these transistors operate in a manner shown in our experiments, which means that by building this example, you're actually building a basic building block of electronics.

4.2 Basic characteristics of transistors

Selecting the correct transistor for a circuit is based on the following characteristics: maximum voltage rating between the collector and the emitter U_{CEmax} , maximum collector current I_{Cmax} and the maximum power rating P_{Cmax} .

If you need to change a faulty transistor, or you feel comfortable enough to build a new circuit, pay attention to these three values. Your circuit must not exceed the maximum rating values of the transistor. If this is disregarded there are possibilities of permanent circuit damage. Besides the values we mentioned, it is sometimes important to know the current amplification, and maximum frequency of operation.

When there is a DC voltage U_{CE} between the collector (C) and emitter (E) with a collector current, the transistor acts as a small electrical heater whose power is given with this equation:

$$P_C = U_{CE} \cdot I_C.$$

Because of that, the transistor is heating itself and everything in its proximity. When U_{CE} or I_C rise (or both of them), the transistor may overheat and become damaged. Maximum power rating

for a transistor, is P_{Cmax} (found in a datasheet). What this means is that the product of U_{CE} and I_C should not be higher than P_{Cmax} :

$$U_{CE} \cdot I_C = P_{Cmax}$$

So, if the voltage across the transistor is increased, the current must be dropped.

For example, maximum ratings for a BC107 transistor are:

$I_{Cmax} = 100mA$,

$U_{CEmax} = 45V$ and

$P_{Cmax} = 300mW$

If we need a $I_C = 60mA$, the maximum voltage is:

$$U_{CE} = \frac{P_{Cmax}}{I_C} = \frac{300mW}{60mA} = 5V.$$

For $U_{CE} = 30V$, the maximum current is:

$$I_C = \frac{P_{Cmax}}{U_{CE}} = \frac{300mW}{30V} = 10mA.$$

Among its other characteristics, this transistor has current amplification coefficient in range between $h_{FE} = 100$ to 450 , and it can be used for frequencies under $300MHz$. According to the recommended values given by the manufacturer, optimum results (stability, low distortion and noise, high gain, etc.) are with $U_{CE} = 5V$ and $I_C = 2mA$.

There are occasions when the heat generated by a transistor cannot be overcome by adjusting voltages and current. In this case the transistors have a metal plate with hole, which is used to attach it to a heat-sink to allow the heat to be passed to a larger surface.

Current amplification is of importance when used in some circuits, where there is a need for equal amplification of two transistors. For example, 2N3055H transistors have h_{FE} within range between 20 and 70 , which means that there is a possibility that one of them has 20 and other 70 . This means that in cases when two identical coefficients are needed, they should be measured. Some multimeters have the option for measuring this, but most don't. Because of this we have provided a simple circuit (4.6) for testing transistors. All you need is an option on your multimeter for measuring DC current up to $5mA$. Both diodes (1N4001, or similar general purpose silicon diodes) and $1k$ resistors are used to protect the instrument if the transistor is "damaged". As we said, current gain is equal to $h_{FE} = I_C / I_B$. In the circuit, when the switch S is pressed, current flows through the base and is approximately equal to $I_B = 10\mu A$, so if the collector current is displayed in milliamps. The gain is equal to:

$$h_{FE} = 100 \cdot I_C$$

For example, if the multimeter shows 2.4mA, $hFE = 2.4 \times 100 = 240$.

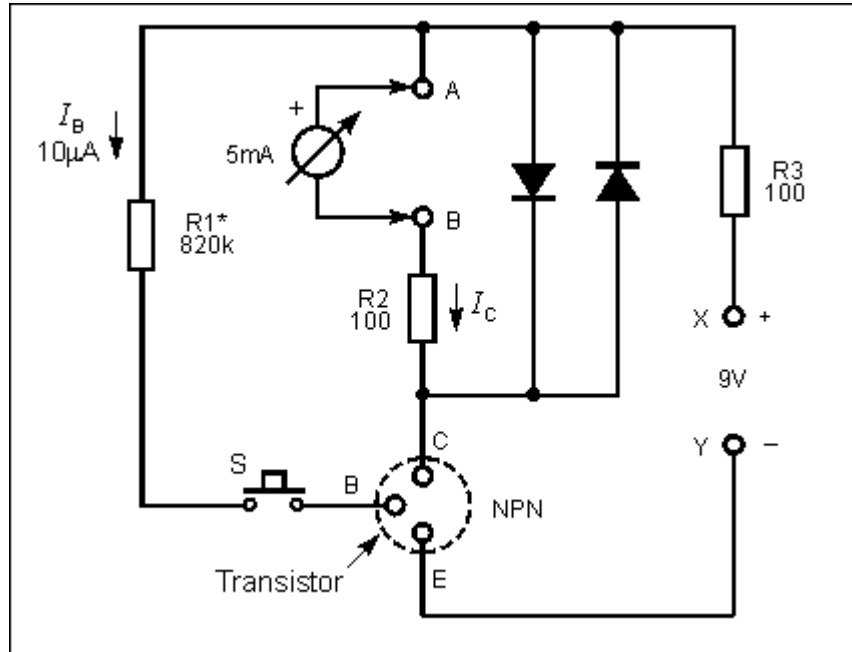


Fig. 4.6: Measuring the hFE

While measuring NPN transistors, the supply should be connected as shown in the diagram. For PNP transistors the battery is reversed. In that case, probes should be reversed as well if you're using analog instrument (one with a needle). If you are using a digital meter (highly recommended) it doesn't matter which probe goes where, but if you do it the same way as you did with NPN there would be a minus in front of the read value, which means that current flows in the opposite direction.

4.3 The safest way to test transistors

Another way to test transistor is to put it into a circuit and detect the operation. The following circuit is a multivibrator. The "test transistor" is T2. The supply voltage can be up to 12v. The LED will blink when a good transistor is fitted to the circuit.

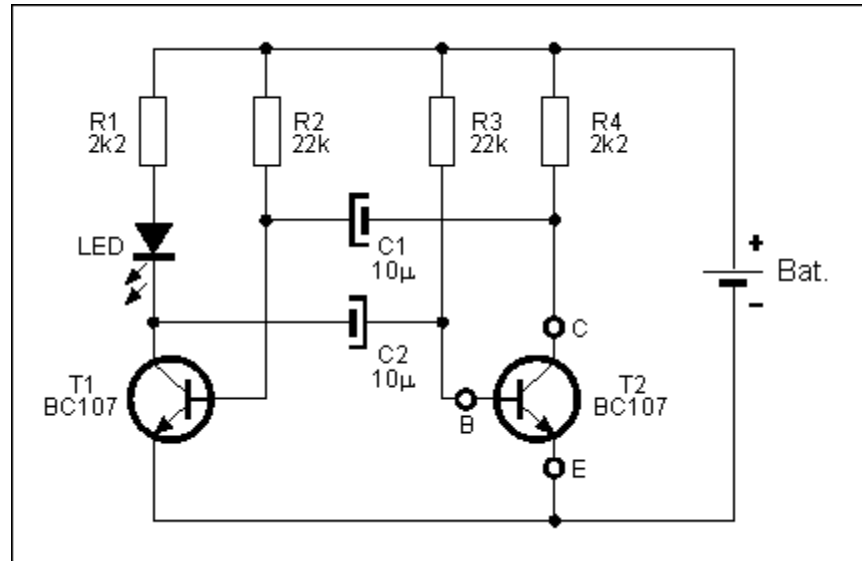


Fig. 4.7: Oscillator to test transistors

To test PNP transistors, same would go, only the transistor which would need to be replaced is the T1, and the battery, LED, C1 and C2 should be reversed.

4.4 TUN and TUP

As we previously said, many electronic devices work perfectly even if the transistor is replaced with a similar device. Because of this, many magazines use the identification TUN and TUP in their schematics. These are general purpose transistors. TUN identifies a general purpose NPN transistor, and TUP is a general purpose PNP transistor.

TUN = Transistor Universal NPN and TUP = Transistor Universal PNP.

These transistors have following characteristics:

U_{CEmax}	20V
I_{Cmax}	100mA
h_{FEmin}	110
P_{Cmax}	100mW
f_{Tmin}	100MHz

Some of the TUNs are:

BC107((8,9)	BC147(8,9)	BC207(8,9)
BC237(8,9)	BC317(8,9)	BC347(8,9)
BC547(8,9)	BC171(2,3)	BC182(3,4)
BC382(3,4)	BC437(8,9)	2N3856A
2N385	2N3860	2N3904 2N3947 2N4124 etc.

Some of the TUPs are:

BC157(8,9)	BC177(8,9)	BC204(5,6)
BC212(3,4)	BC251(2,3)	BC261(2,3)
BC307(8,9)	BC320(1,2)	BC350(1,2)
BC512(3,4)	BC557(8,9)	BC416
2N2412	2N3251	2N3906 2N4126 2N4291 etc.

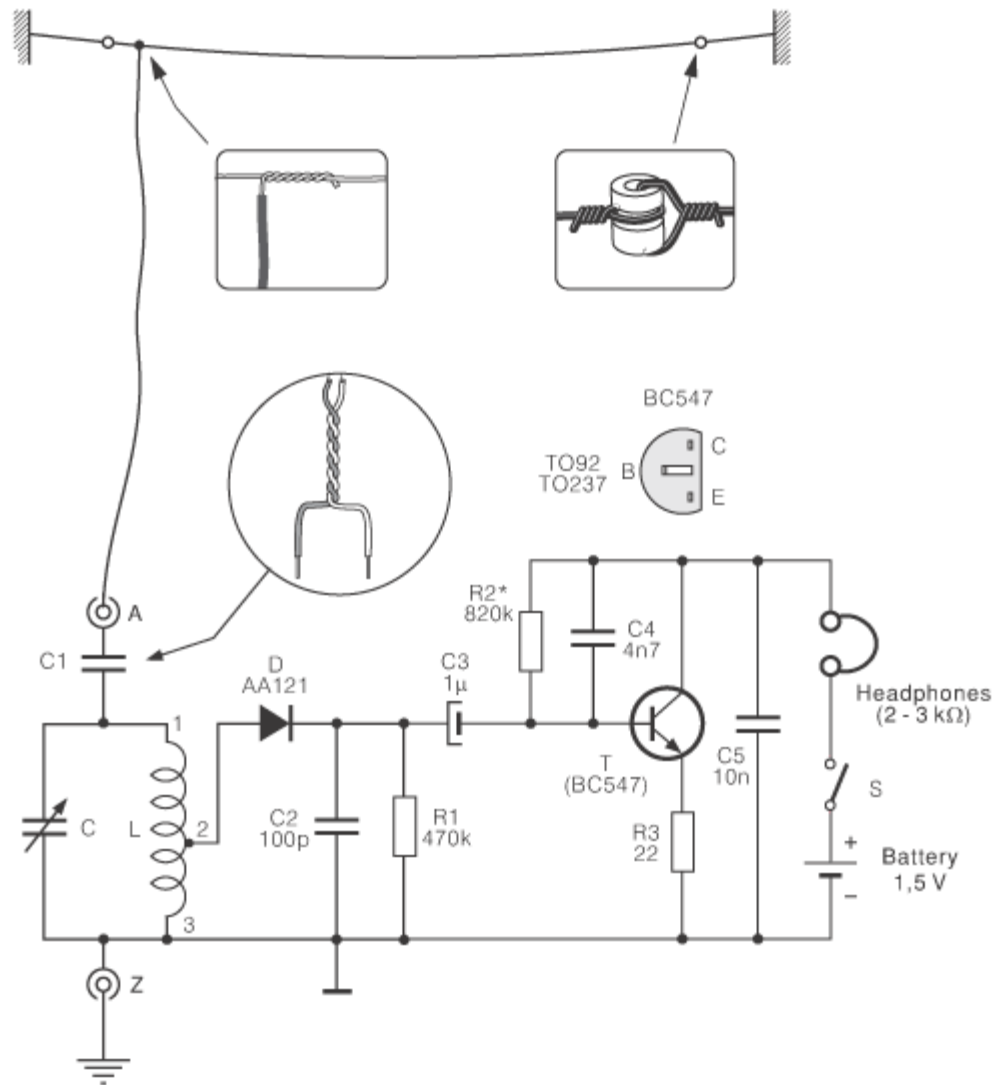
4.5 Practical example

The most common role of a transistor in an analog circuit is as an active (amplifying) component. Diagram 4.8 shows a simple radio receiver - commonly called a "Crystal Set with amplifier."

Variable capacitor C and coil L form a parallel oscillating circuit which is used to pick out the signal of a radio station out of many different signals of different frequencies. A diode, 100pF capacitor and a 470k resistor form a diode detector which is used to transform the low frequency voltage into information (music, speech). Information across the 470k resistor passes through a 1uF capacitor to the base of a transistor. The transistor and its associated components create a low frequency amplifier which amplifies the signal.

On figure 4.8 there are symbols for a common ground and grounding. Beginners usually assume these two are the same which is a mistake. On the circuit board the common ground is a copper track whose size is significantly wider than the other tracks. When this radio receiver is built on a circuit board, common ground is a copper strip connecting holes where the lower end of the capacitor C, coil L 100pF capacitor and 470k resistor are soldered. On the other hand, grounding is a metal rod stuck in a wet earth (connecting your circuits grounding point to the plumbing or heating system of your house is also a good way to ground your project).

Resistor R2 biases the transistor. This voltage should be around 0.7V, so that voltage on the collector is approximately equal to half the battery voltage.



C1 - 5pF.....30 pF
 C2 - 100pF.....1nF
 C3 - 470nF.....5μF
 L - 0,35 mH
 C - $C_{min}=12pF$, $C_{max}=218pF$
 R1 - 500kΩ.....50 kΩ
 R2 - 500 kΩ.....2,2 MΩ
 D - DUG (AA112, AA116, AA121, 1N34)
 T - TUN (BC547, BC107,8,9 i sl.)

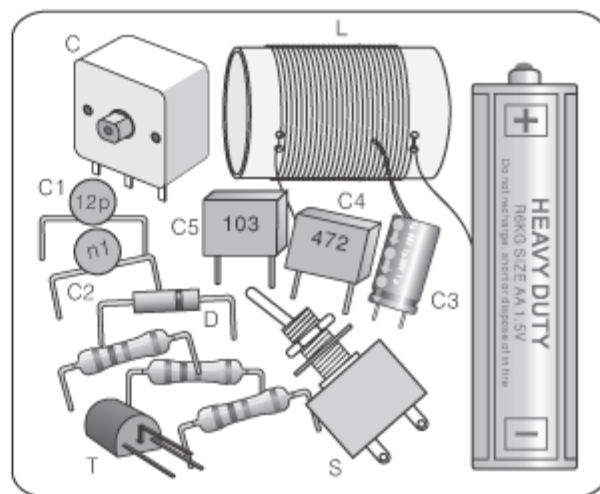


Fig. 4.8: Detector receiver with a simple amplifier

5. Diodes

As with transistors, diodes are fabricated from semi-conducting material. So, the first letter in their identification is A for germanium diode or B for silicon diode. They can be encased in glass, metal or a plastic housing. They have two leads: cathode (k) and an anode (A). The most important property of all diodes is their resistance is very low in one direction and very large in the opposite direction.

When a diode is measured with a multimeter and it reads a low value of ohms, this is not really the resistance of the diode. It represents the voltage drop across the junction of the diode. This means a multimeter can only be used to detect if the junction is not damaged. If the reading is low in one direction and very high in the other direction, the diode is operational.

When a diode is placed in a circuit and the voltage on the anode is higher than the cathode, it acts like a low value resistor and current will flow.

If it is connected in the opposite direction it acts like a large value resistor and current does not flow.

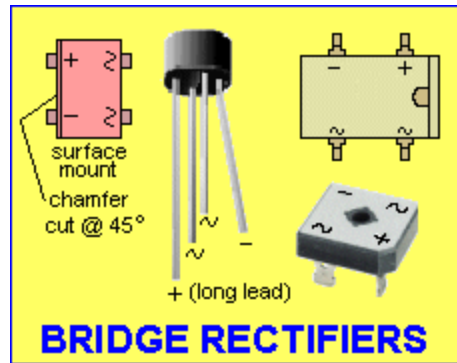
In the first case the diode is said to be "forward biased" and in the second case it is "reverse biased."

Figure 5.1 shows several different diodes:



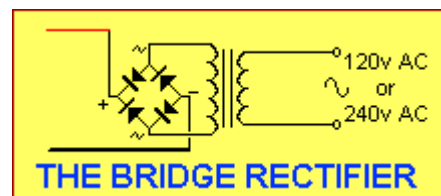
Fig. 5.1: Several different types of diodes

The diodes above are all single diodes, however 4 diodes are available in a single package. This is called a BRIDGE or BRIDGE RECTIFIER. Examples of a bridge are shown in the diagram below:

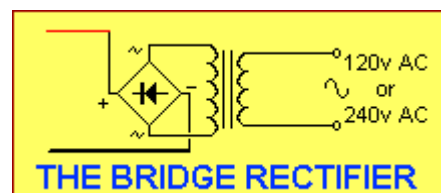


You must be able to identify each of the 4 leads on a bridge so that it can be inserted into a circuit around the correct way. The surface-mount device above is identified by a cut @ 45° along one side. The leaded bridge has one leg longer than the others and the top is marked with AC marks and "+." The high-current bridge has a corner cut off and the other surface-mount device has a cut or notch at one end.

These devices are added to a circuit as shown in the next diagram:



The 4 diodes face the same direction and this means a single diode can be shown on the circuit diagram:



Symbols in 5.2 show a number of diodes. There are a number of specially-designed diodes: for high current, high-speed, low voltage-drop, light-detection, and varying capacitance as the voltage is altered. Most diodes are made from silicon as it will withstand high temperature, however germanium is used if a low voltage-drop is required. There is also a light emitting diode called a LED, but this is a completely different type of diode.











K(cathode) A(anode) k  <i>a.</i>	 <i>b.</i>	 <i>c.</i>	 <i>d.</i>	 <i>e.</i>
 <i>f.</i>	 <i>g.</i>	 <i>h.</i>	 <i>i.</i>	 <i>j.</i>

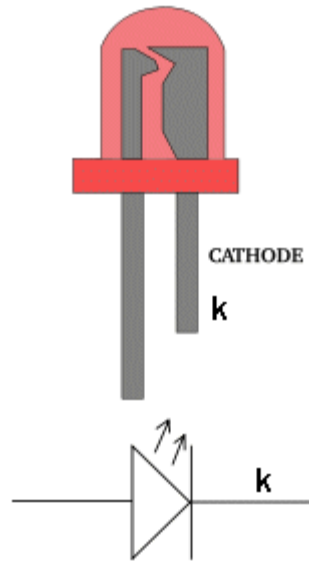
Fig. 5.2: Diode symbols: a - standard diode, b - LED, c, d - Zener, e - photo, f,g - tunnel, h - Schottky, i - breakdown, j - capacitive

LEDs (Light Emitting Diodes) are constructed from a crystalline substance that emits light when a current flows through it. Depending on the crystalline material: red, yellow, green, blue or orange light is produced. The photo below shows some of the colours hat can be produced by LEDs:



It is not possible to produce white light from any of these materials, so a triad of red, blue and green is placed inside a case and they are all illuminated at the same time to produce white light. Recently, while light has been produced from a LED by a very complex and interesting process that can be found on Wikipedia: <http://en.wikipedia.org/wiki/LED>

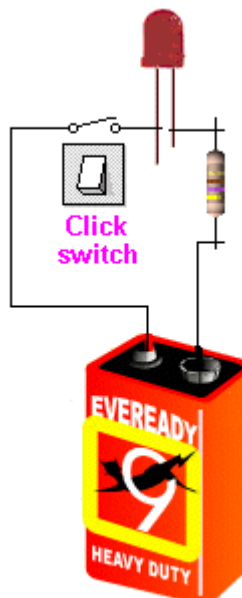
LEDs have a cathode and anode lead and must be connected to DC around the correct way. The cathode lead is identified on the body by a flat-spot on the side of the LED. The cathode lead is the shorter lead.



One of the most important things to remember about a LED is the characteristic voltage that appears across it when connected to a voltage. This does not change with brightness and cannot be altered.

For a red LED, this voltage is 1.7v and if you supply it with more than this voltage, it will be damaged.

The easy solution is to place a resistor on one lead as shown in the diagram below:



The LED will allow the exact voltage to appear across it and the brightness will depend on the value of the resistor.

Zener diodes (5.2c and 5.2d) are designed to stabilize a voltage. Diodes marked as ZPD5.6V or ZPY15V have operating voltages of 5.6V and 15V.

Photo diodes (5.2e) are constructed in a way that they allow light to fall on the P-N connection. When there is no light, a photo diode acts as a regular diode. It has high resistance in one direction, and low resistance in opposite direction. When there is light, both resistances are low. Photo diodes and LEDs are the main items in an optocoupler (to be discussed in more detail in chapter 9).

Tunnel diodes (5.2f and 5.2g) are commonly used in oscillators for very high frequencies.

Schottky diodes (5.2h) are used in high frequency circuits and for its low voltage drop in the forward direction.

Breakdown diodes (5.2i) are actually Zener diodes. They are used in various devices for protection and voltage regulation. It passes current only when voltage rises above a pre-defined value.

A Varicap diode (5.2j) is used instead of a variable capacitor in high frequency circuits. When the voltage across it is changed, the capacitance between cathode and anode is changed. This diode is commonly used in radio receivers, transceivers and oscillators.

The cathode of a low power diode is marked with a ring painted on the case, but it is worth noting that some manufacturers label the anode this way, so it is best to test it with a multimeter.

Power diodes are marked with a symbol engraved on the housing. If a diode is housed in a metal package, the case is generally the cathode and anode is the lead coming from the housing.

5.1 Diode identification

European diodes are marked using two or three letters and a number. The first letter is used to identify the material used in manufacturing the component (A - germanium, B - silicon), or, in case of letter Z, a Zener diode.

The second and third letters specify the type and usage of the diode. Some of the varieties are: A - low power diode, like the AA111, AA113, AA121, etc. - they are used in the detector of a radio receiver; BA124, BA125 : varicap diodes used instead of variable capacitors in receiving devices, oscillators, etc., BAY80, BAY93, etc. - switching diodes used in devices using logic circuits. BA157, BA158, etc. - these are switching diodes with short recovery time.

B - two capacitive (varicap) diodes in the same housing, like BB104, BB105, etc.

Y - regulation diodes, like BY240, BY243, BY244, etc. - these regulation diodes come in a plastic packaging and operate on a maximum current of 0.8A. If there is another Y, the diode is intended for higher current. For example, BYY44 is a diode whose absolute maximum current rating is 1A. When Y is the second letter in a Zener diode mark (ZY10, ZY30, etc.) it means it is intended for higher current.

G, G, PD - different tolerance marks for Zener diodes. Some of these are ZF12 (5% tolerance),

ZG18 (10% tolerance), ZPD9.1 (5% tolerance).

The third letter is used to specify a property (high current, for example).

American markings begin with 1N followed by a number, 1N4001, for example (regulating diode), 1N4449 (switching diode), etc.

Japanese style is similar to American, the main difference is that instead of N there is S, 1S241 being one of them.

5.2 Diode characteristics

The most important characteristics when using power diodes is the maximum current in the forward direction (I_{Fmax}), and maximum voltage in the reverse direction (U_{Rmax}).

The important characteristics for a Zener diode are Zener voltage (U_Z), Zener current (I_Z) and maximum dissipation power (P_D).

When working with capacitive diodes it is important to know their maximum and minimum capacitance, as well as values of DC voltage during which these capacitances occur.

With LEDs it is important to know the maximum value of current it is capable of passing. The natural characteristic voltage across a LED depends on the colour and starts at 1.7V for red to more than 2.4V for green and blue.

Current starts at 1mA for a very small glow and goes to about 40mA. High brightness LEDs and "power LEDs" require up to 1 amp and more. You must know the exact current required by the LED you are using as the wrong dropper resistor will allow too much current to flow and the LED will be damaged **instantly**.

The value of this resistors will be covered in another chapter.

Beside universal transistors TUN and TUP (mentioned in Chapter 4.4), there are universal diodes as well. They are marked with DUS (for universal silicon diode) and DUG (for germanium) on circuit diagrams.

DUS = Diode Universal Silicon DUG = Diode Universal Germanium

5.3 Practical examples

The diagram of a power supply in figure (3.8) uses several diodes. The first four are in a single package, identified by B40C1500. This is a bridge rectifier.

The LED in the circuit indicates the transformer is working. Resistor R1 is used to limit the current through the LED and the brightness of the LED indicates the approximate voltage.

Diodes marked 1N4002 protect the integrated circuit.

Figure 5.3 below shows some other examples of diodes. The life of a globe can be increased by adding a diode as shown in 5.3a. By simply connecting it in series, the current passing through the globe is halved and it lasts a lot longer. However the brightness is reduced and the light becomes yellow. The Diode should have a reverse voltage of over 400V, and a current higher

than the globe. A 1N4004 or BY244 is suitable.

A very simple DC voltage stabilizer for low currents can be made using 5.3c as a reference.

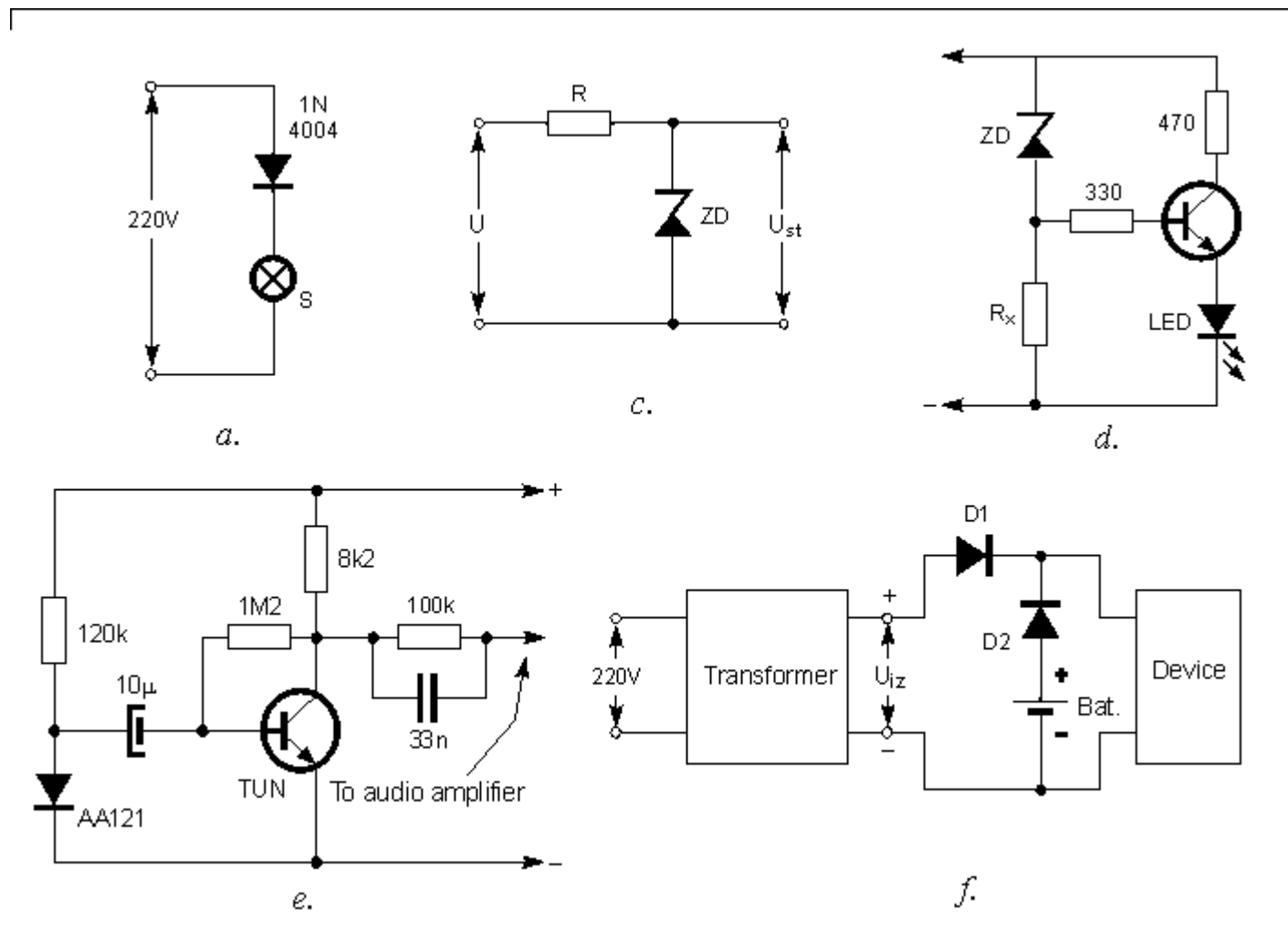


Fig. 5.3: a - using a diode to prolong the light bulb's life span, b - stair-light LED indicator, c - voltage stabilizer, d - voltage rise indicator, e - rain noise synthesizer, f - backup supply

Unstabilized voltage is marked "U", and stabilized with "UST." Voltage on the Zener diode is equal to UST, so if we want to achieve a stabilized 9V, we would use a ZPD9.1 diode. Although this stabilizer has limited use it is the basis of all designs found in power supplies.

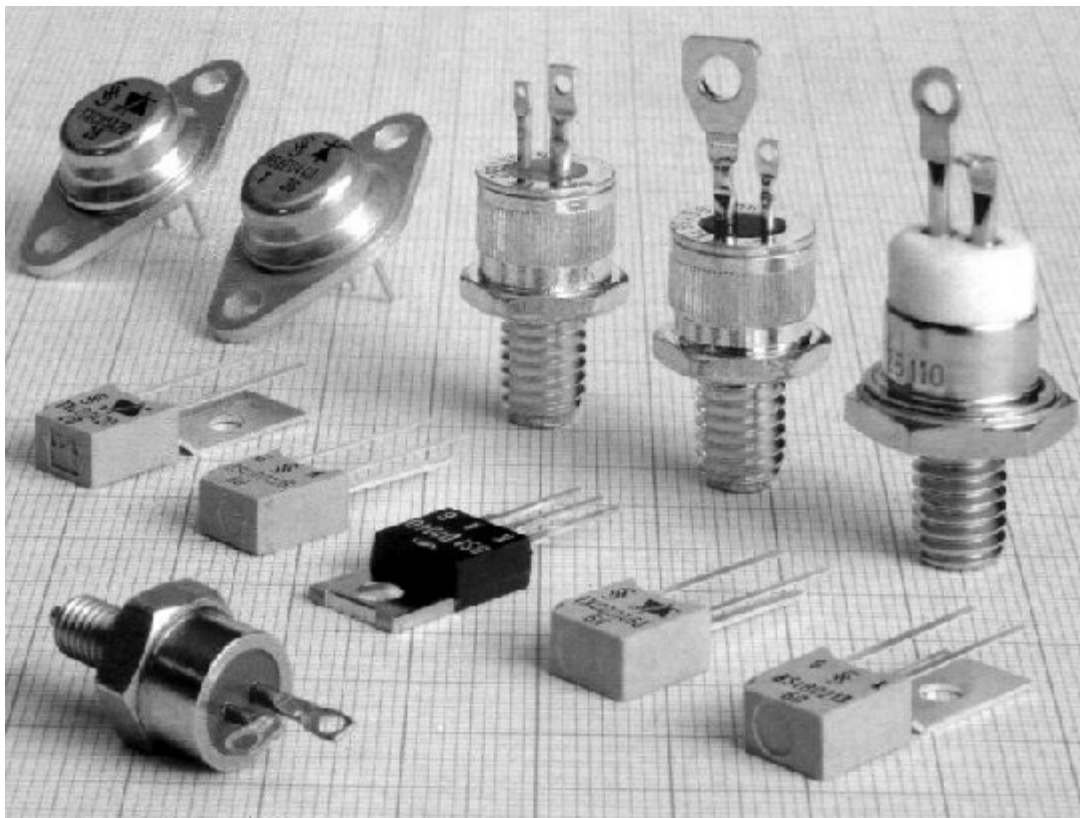
We can also devise a voltage overload detector as shown in figure 5.3d. A LED indicates when a voltage is over a predefined value. When the voltage is lower than the operating voltage of the Zener, the zener acts as a high value resistor, so DC voltage on the base of the transistor is very low, and the transistor does not "turn on." When the voltage rises to equal the Zener voltage, its resistance is lowered, and transistor receives current on its base and it turns on to illuminate the LED. This example uses a 6V Zener diode, which means that the LED is illuminated when the voltage reaches that value. For other voltage values, different Zener diodes should be used.

Brightness and the exact moment of illuminating the LED can be set with the value of R_x . To modify this circuit so that it signals when a voltage drops below some predefined level, the Zener diode and R_x are swapped. For example, by using a 12V Zener diode, we can make a car battery level indicator. So, when the voltage drops below 12V, the battery is ready for recharge. Figure 5.3e shows a noise-producing circuit, which produces a rain-like sound. DC current flowing through diode AA121 isn't absolutely constant and this creates the noise which is amplified by the transistor (any NPN transistor) and passed to a filter (resistor-capacitor circuit with values 33nF and 100k).

Figure 5.3f shows a battery back-up circuit. When the "supply" fails, the battery takes over.

6. Thyristors, triacs, diacs

There are several thyristors displayed on 6.1. Triacs look the same, while diacs look like small power rectifying diodes. Their symbols, and pin-out is found in figure 6.2.



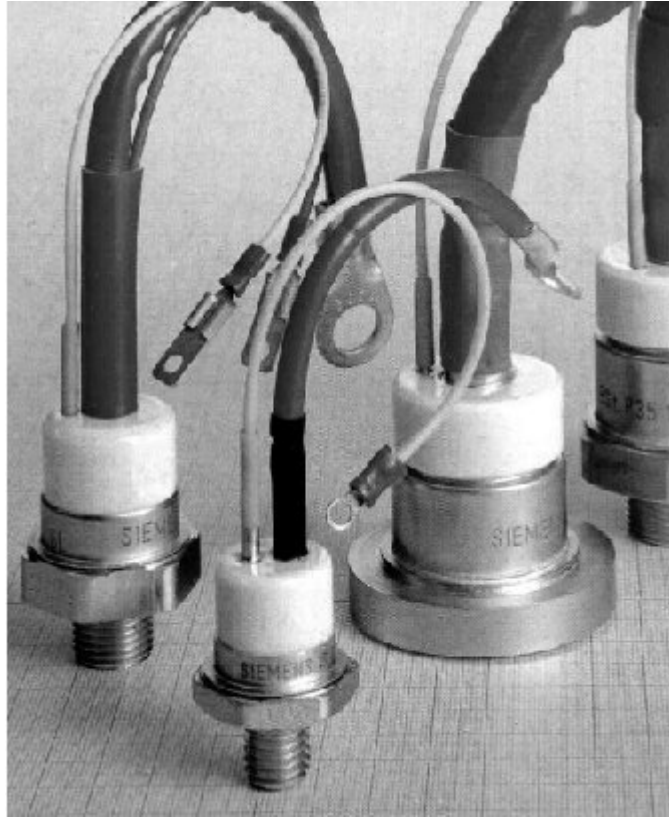


Fig. 6.1: Several thyristors and triacs

A thyristor is an improved diode. Besides anode (A) and cathode (k) it has another lead which is commonly described as a gate (G), as found on picture 6.2a. The same way a diode does, a thyristor conducts current when the anode is positive compared to the cathode, but only if the voltage on the gate is positive and sufficient current is flowing into the gate to turn on the device. When a thyristor starts conducting current into the gate is of no importance and thyristor can only be switched off by removing the current between anode and cathode. For example, see figure 6.3. If S1 is closed, the thyristor will not conduct, and the globe will not light. If S2 is closed for a very short time, the globe will illuminate. To turn off the globe, S1 must be opened. Thyristors are marked in some circuits as SCR, which is an acronym for Silicon Controlled Rectifier.

A triac is very similar to a thyristor, with the difference that it can conduct in both directions. It has three electrodes, called anode 1 (A1), anode 2 (A2), and gate (G). It is used for regulation of alternating current circuits. Devices such as hand drills or globes can be controlled with a triac.

Thyristors and triacs are marked alphanumerically, KT430, for example.

Low power thyristors and triacs are packed in same housings as transistors, but high power devices have a completely different housing. These are shown in figure 6.1. Pin-outs of some common thyristors and triacs are shown in 6.2 a and b.

Diacs (6.2c), or two-way diodes as they are often referred to, are used together with thyristors and triacs. Their main property is that their resistance is very large until voltage on their ends exceeds some predefined value. When the voltage is under this value, a diac responds as a large value resistor, and when voltage rises it acts as a low value resistor.

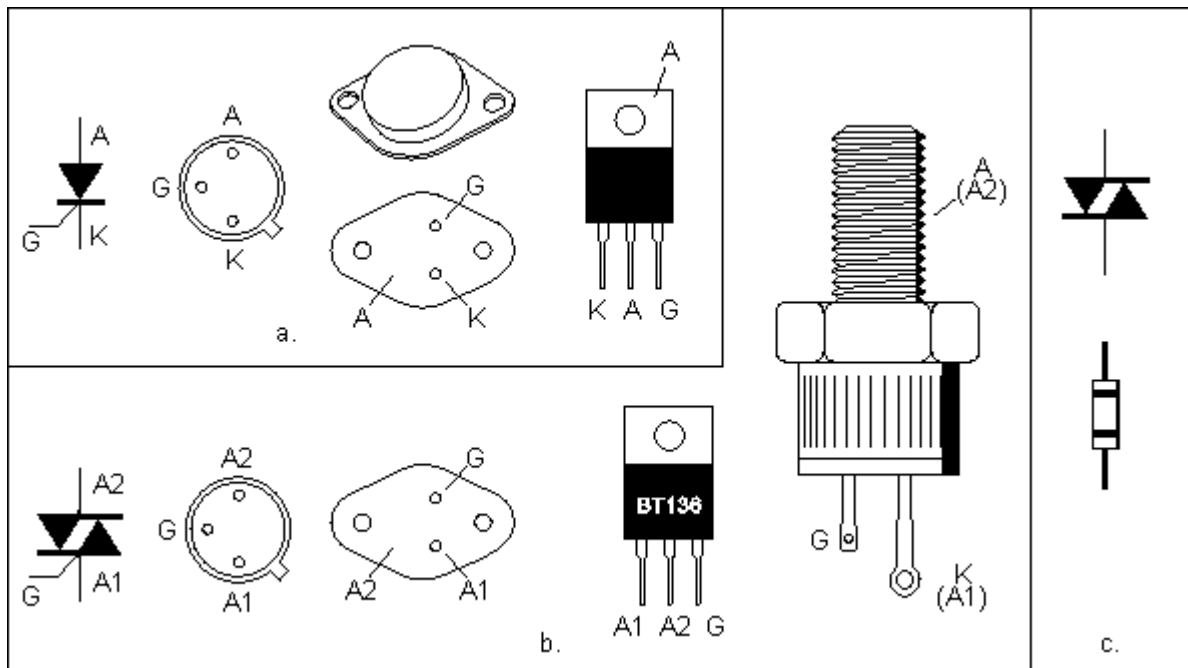


Fig. 6.2: Symbols and pin placements for: a - thyristor, b - triac, c - diac

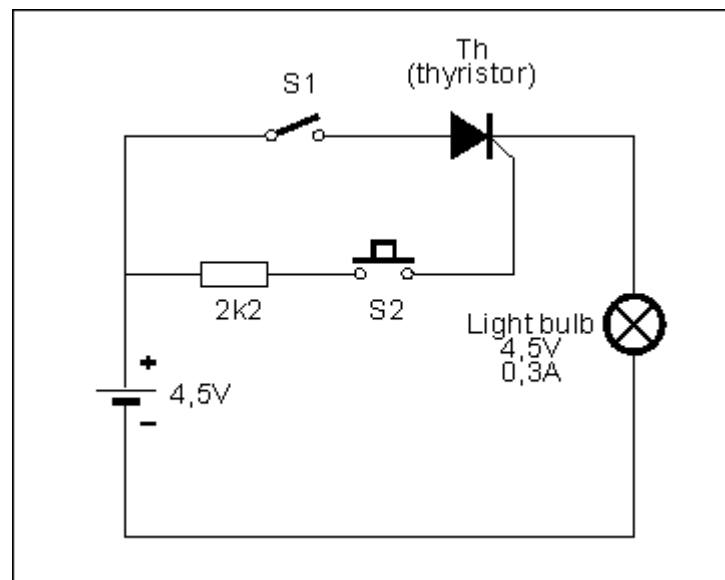


Fig. 6.3: Thyristor principle of work

6.1 Practical examples

Picture 6.5 detects when light is present in a room. With no light, the photo-transistor does not conduct. When light is present, the photo-transistor conducts and the bell is activated. Turning off the light will not stop the alarm. The alarm is turned off via S1.

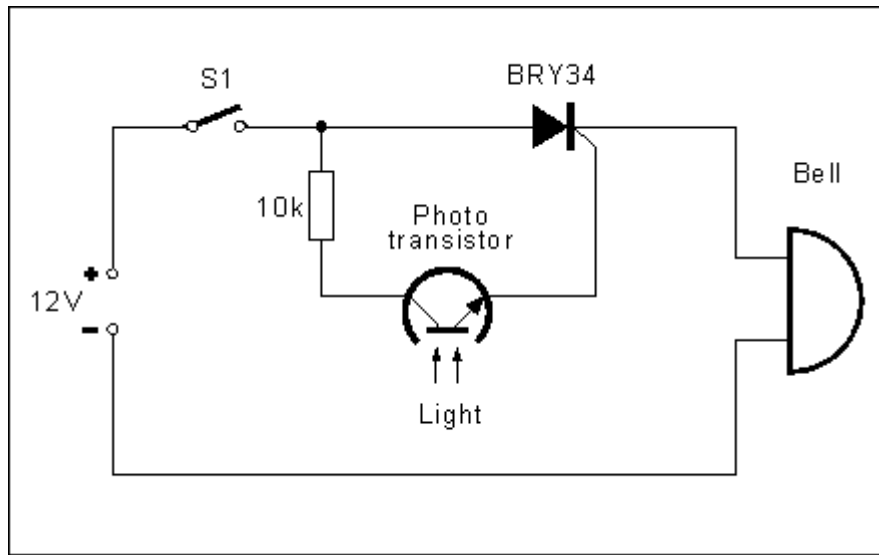
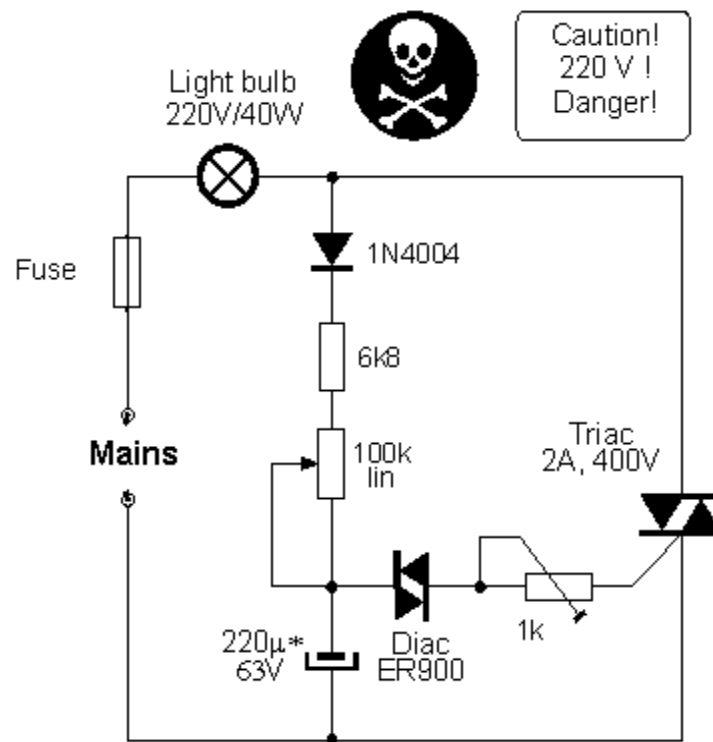


Fig. 6.5: Alarm device using a thyristor and a photo-transistor

A circuit to flash a globe is shown in figure 6.6. This circuit flashes a 40w globe several times per second. Mains voltage is regulated using the 1N4004 diode. The 220u capacitor charges and its voltage rises. When this voltage reaches the design-voltage of the diac (20v), the capacitor discharges through the diac and into the triac. This switches the triac on and lights the bulb for a very short period of time, after a period of time (set by the 100k pot), the capacitor is charged again, and the whole cycle repeats. The 1k trim pot sets the current level which is needed to trigger the triac.



* Capacitor voltage must be higher than maximum diac voltage

Fig. 6.6: Flasher

A circuit to control the brightness of a globe or the speed of a motor is shown in figure 6.7

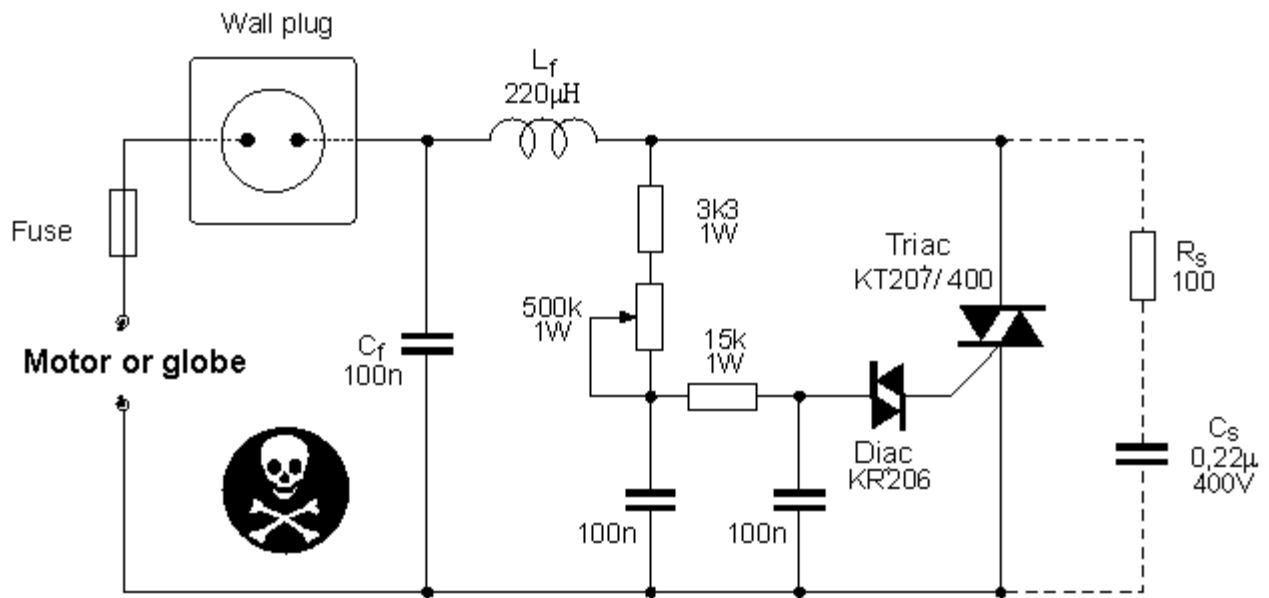


Fig. 6.7: Light bulb intensity or motor speed controller

If the main use for this circuit is to control the brightness of a light bulb, R_s and C_s are not necessary.

7. Integrated circuits

Integrated Circuits play a very important part in electronics. Most are specially made for a specific task and contain up to thousands of transistors, diodes and resistors. Special purposes IC's such as audio-amplifiers, FM radios, logic blocks, regulators and even a whole micro computers in the form of a micro controller can be fitted inside a tiny package. Some of the simple Integrated Circuits are shown in figure 7.1.

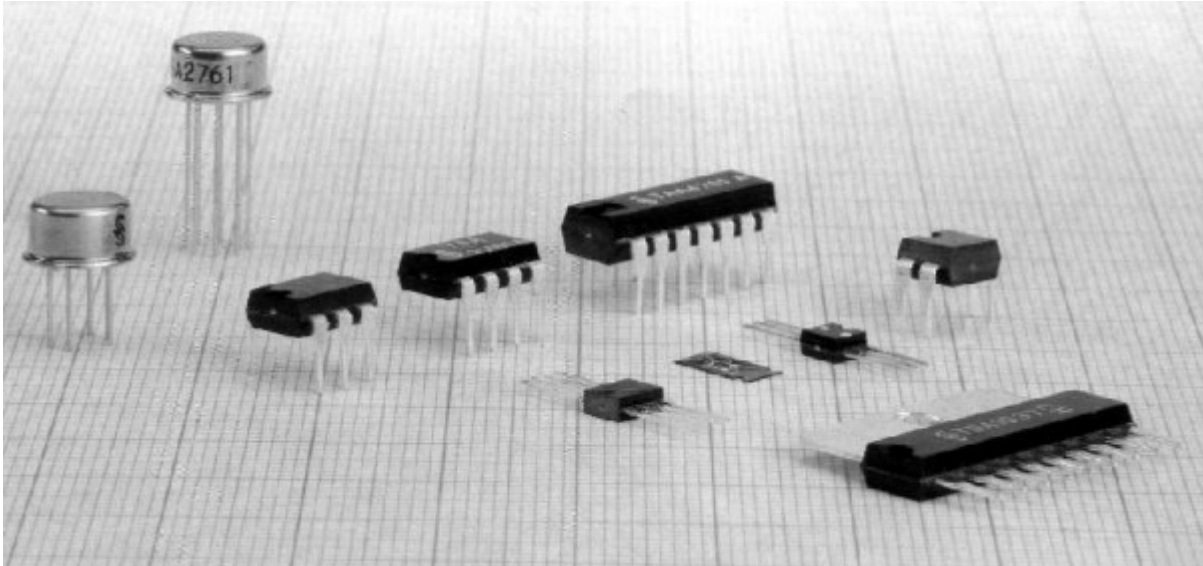


Fig. 7.1: Integrated circuits

Depending on the way they are manufactured, integrated circuits can be divided into two groups: hybrid and monolithic. Hybrid circuits have been around longer. If a transistor is opened, the crystal inside is very small. This means a transistor doesn't take up very much space and many of them can be fitted into a single Integrated Circuit.

The pin-out for some of the common packages is shown in Figure 7.2:

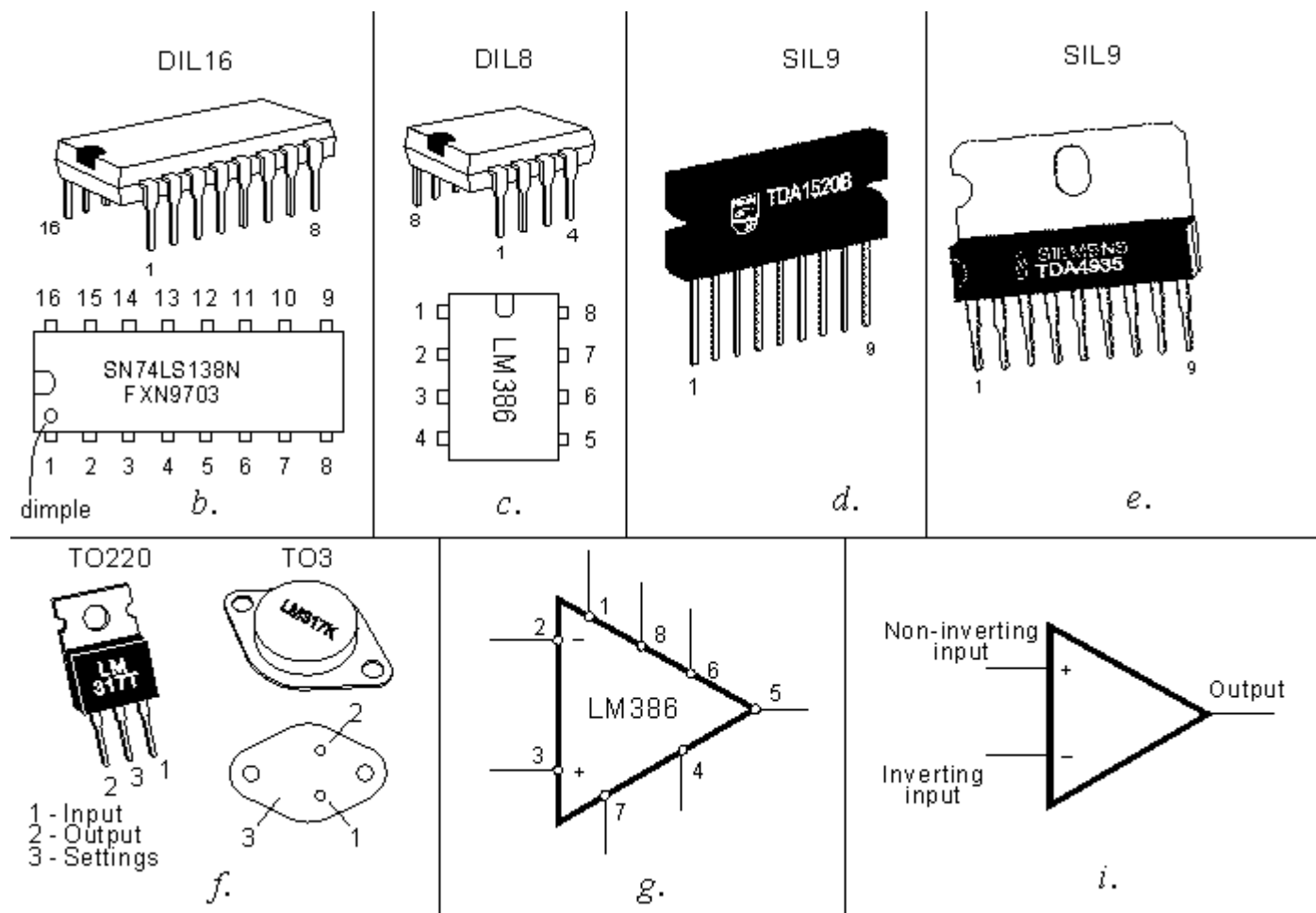


Fig. 7.2: Pin-out and symbols for some common integrated circuits

Most integrated Circuits are in a DIL package - Dual In Line, meaning there are two rows of pins. (DIL16 and DIL8 are shown in 7.2b and 7.2c). The device is viewed from the top and the pins are numbered in an anti-clockwise direction.

High power integrated circuits can generate a lot of heat and they have a metal tag that can be connected to a heatsink to dissipate the heat. Examples of these IC's are shown in 7.2d and 7.2e, and 7.2f.

Symbols used to represent integrated circuits are shown in 7.2g and 7.2i. Symbol 7.2g is commonly used to represent amplifiers.

Figure 7.2i shows an operational amplifier. Signs + and - represent inverting and non-inverting inputs. The signal to be amplified is applied between one of the inputs and ground (ground and supply aren't represented, but are necessary for the circuit to operate).

Integrated circuits can be divided into two further groups: **analog (linear) and digital**. The output voltage of a linear circuits is continuous, and follows changes in the input. Typical representative of a linear IC is an integrated audio amplifier. When a signal from a microphone is connected to the input the output will vary in the same way as the voltage from the microphone. If watched on an oscilloscope, the signal on the output will be the same shape as the mic's signal,

only the voltage will be higher depending on the amplification of the integrated circuit. It is a different situation with digital IC's. Their output voltage is not continuous. It is either LOW or HIGH and it changes from one state to the other very quickly.

7.1 Analog integrated circuits

While on the topic of analog circuits, we will look at the LM386 IC. It has all the components for a complete audio-amplifier. Figure 7.3a shows an example of an amplifier made with this integrated circuit, which can be used as a complete amplifier for a walkman, interphone, cassette player or some other audio device. It can also be used as a test circuit for troubleshooting.

One of the essential components in this circuit is the 100nF capacitor which is placed between pin 6 (which is connected to the positive of the supply) and ground. The capacitor should be ceramic and should be mounted as close to the integrated circuit as possible. This is common practice when working with integrated circuits, even when it isn't shown in the diagram as a capacitor connected between the positive and negative stabilizes the voltage and protects the circuit from spikes and a phenomenon called instability. This is due to inductance in the power supply tracks allowing high currents taken by the IC to upset its operation.

7.2 Digital integrated circuits

The CD4011 will be our "show-and-tell" IC to cover the main characteristics of digital circuits. It is a 14 pin DIL package. The pin-out is shown in figure 7.4a. Note the small half-round slit on one end of the IC. It identifies pin 1. Pins 7 and 14 connect to a supply (battery or DC power supply). Negative is connected to pin 7. Positive is connected to pin 14.

There are four logic NAND gates in a CD4011 IC. Each has two inputs and one output. For gate N1 the inputs are pins 1 and 2, and output is pin 3. The symbol for a NAND gate is displayed in figure 7.4b. The inputs are marked A and B and output is F. The supply voltage can be up to 16v and as low as 5V. The output will deliver up to 10mA at 12v but this is reduced as the supply voltage is reduced.

Figure 7.4b shows the truth table for a NAND gate. It shows the output voltage (voltage between F and ground) with different input states. Because there are only two voltages for every pin, we call them states, with logic zero when the voltage is zero, and logic one when the voltage on the pin is the same as the supply voltage.

From this we can read the second row of the truth table: if logic zero is on both input pins, output is logic one, third row is similar: if the first input is one, and the second one is zero, output is logic one, fourth row: if the first input is zero, and the second one is one, output is logic one. Fifth row is different, since both of its inputs are one, the definition of NAND gate states that the output is zero.

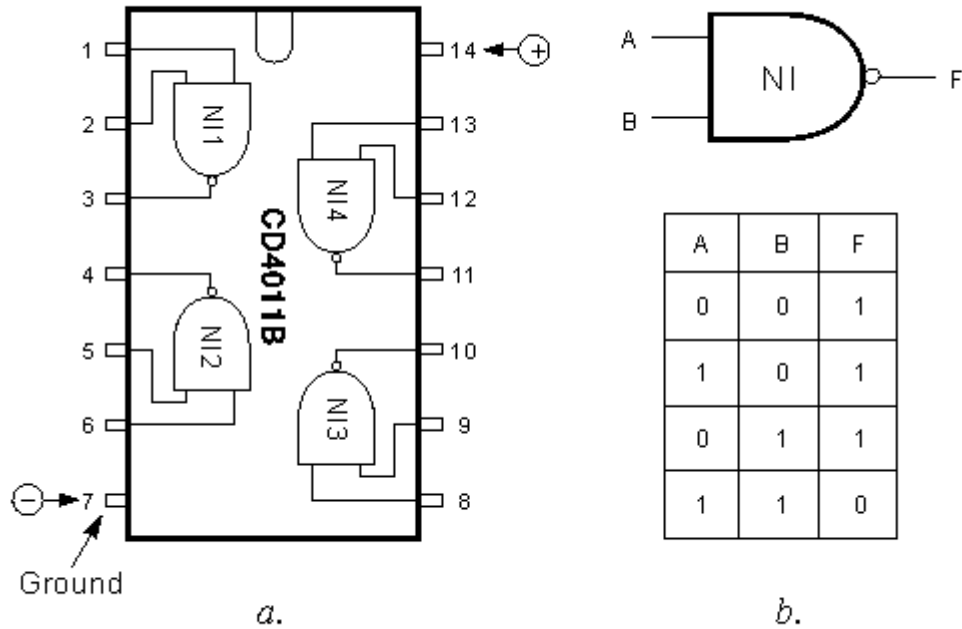
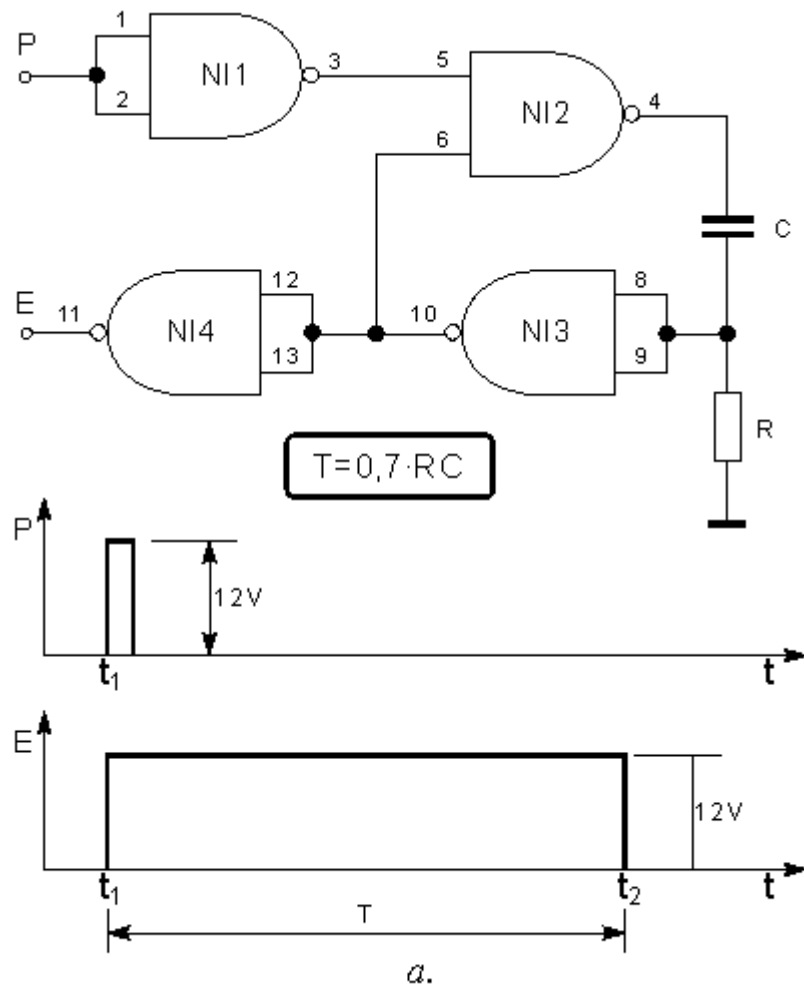


Fig. 7.4: a - 4011 pin placements, b - symbol and the truth table for NAND gates,

Logic circuits have many applications, but their main use is in computer circuits.

The following circuit is a simple example to show how the gates can be connected to produce a project that turns on a globe when a finger is placed on a "touch pad."

The globe turns off after a period of time, determined by the value of the 470u and 2M2 resistor.



The operation of a NAND gate

Lets look at the functionalities of the following circuit. Both inputs of NI1 are connected to each other, so when input P is HIGH, output is zero. This logic zero is passed on to NI2, so no matter what is on the input 6, output 4 is logic one. This means that, between the ground and pin 4, the voltage is equal to 12V.

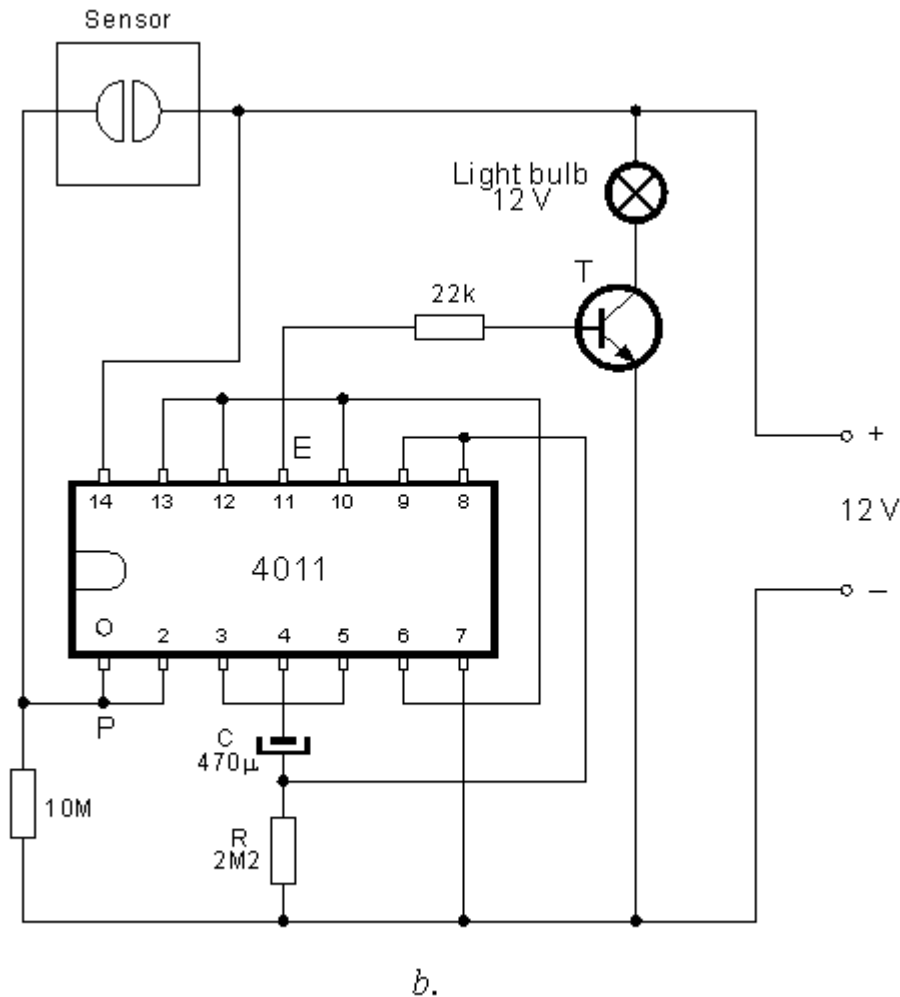


Fig. 7.5: Sensor switch using a 4011

Current flows through capacitor C and resistor R, so capacitor begins to charge. Every uncharged capacitor behaves like a short circuit. Because of that, when 12V appears on pin 4, it is also present on resistor R and also on pins 8 and 9. Pin 10 shows logic zero because of this which is connected to pin 6. From now on, logic zero on pin 5 is no longer needed because only one input needs to be zero for the output to be logic one. So input P is no longer needed. Gates NI2 and NI3 maintain logic zero on pin 4. How long will this last? It depends on the value of the capacitor and resistor. As the capacitor charges, the voltage on the resistor drops and when it falls to 1/2 of the supply voltage (6V in our case), NI3 detects a low on its inputs so logic one appears on pin 10. Since logic one is now on input 5 (no logic one present on P), and on input 6, output 4 is zero, capacitor dumps its charge via diodes on the inputs on pins 8 and 9 and the circuit starts operating again.

As we saw, for a certain period of time, which is equal to $T=0.7*RC$ output of pin 10 was logic zero. During that time output E (pin 11) is logic one. For example, if $R = 2M2$ and $C=47\mu F$, for time $T = 2.2*10^6*47*10^{-6} = 94$ sec from the moment impulse on input P subsided, voltage on

output E is 12V.

The end result of our experiment is on diagram 7.5a. Short positive pulses appearing on P in the time t_1 caused a longer variable pulse on output E.

Schematic 7.5b displays this circuit which allows us to light a bulb using four NAND gates interconnected in the way shown on picture 7.5a.

The sensor is two copper (or some other conducting material) plates glued to some non-conducting material (plastics, wood, etc.) in close proximity to each other. So, when we touch the sensor with the tip of our finger, we close the circuit. 12V appears on input P, which in turn conducts the voltage to the output E, resistor $R = 22k$ conducts base current and the bulb lights. When we remove our finger, output E will last for 94 seconds, after which it goes to logic zero and the light goes out.

Transistor T is selected so that its maximum allowed collector current is higher than the current of the globe.

(The globe's current flow value is found by dividing its power by its voltage. For example, if its power is $P = 6W$ and voltage is $U = 12V$, current through the globe is $I = P/U = 6W/12V = 0.5A$ or higher. One thing you must remember with a globe is the starting or "turn-on" current. It is about six times the operating current and the transistor must be able to pass this current for the globe to illuminate.

7.3 Practical examples

Diagram 7.6 shows a circuit for a stereo audio-amp using a TDA4935 IC. It is a modern integrated circuit with two separate pre-amps and stereo outputs.

Left and right input signals are marked UL and UD, which are brought to two inputs of the amplifier. The chip also has built-in heat and overload protection. Maximum output for each amplifier is 15W, so they can be used in stereo mode of 2x15W amplifiers.

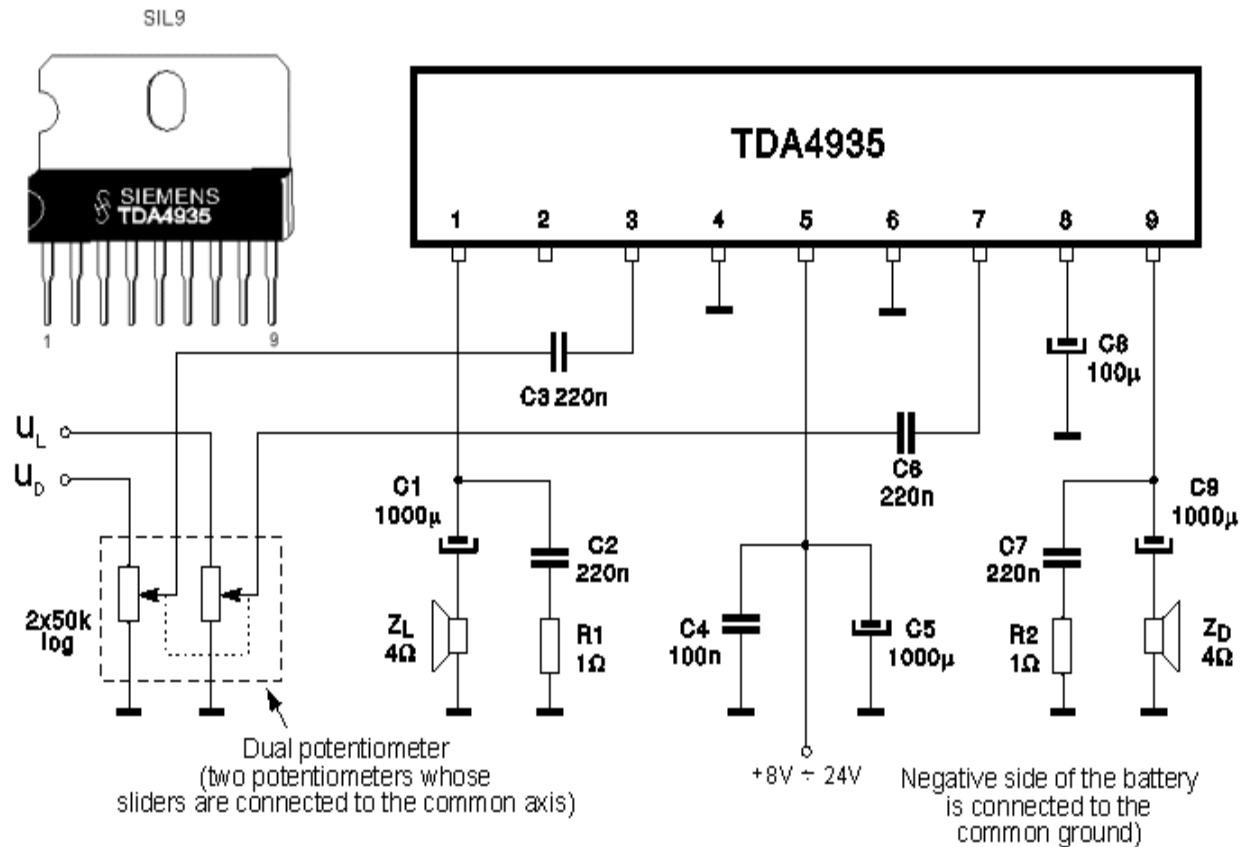


Fig. 7.6: Stereo audio-amplifier using the TDA4935

Another example is an audio amplifier using an LM386 circuit, with a preamp using a BC107 transistor. The series connected capacitor and resistor between pins 1 and 5 produces low frequency amplification (around 100Hz) improving the characteristics of the circuit. This amplifier could be used with any low frequency source (gramophone, microphone, etc.).

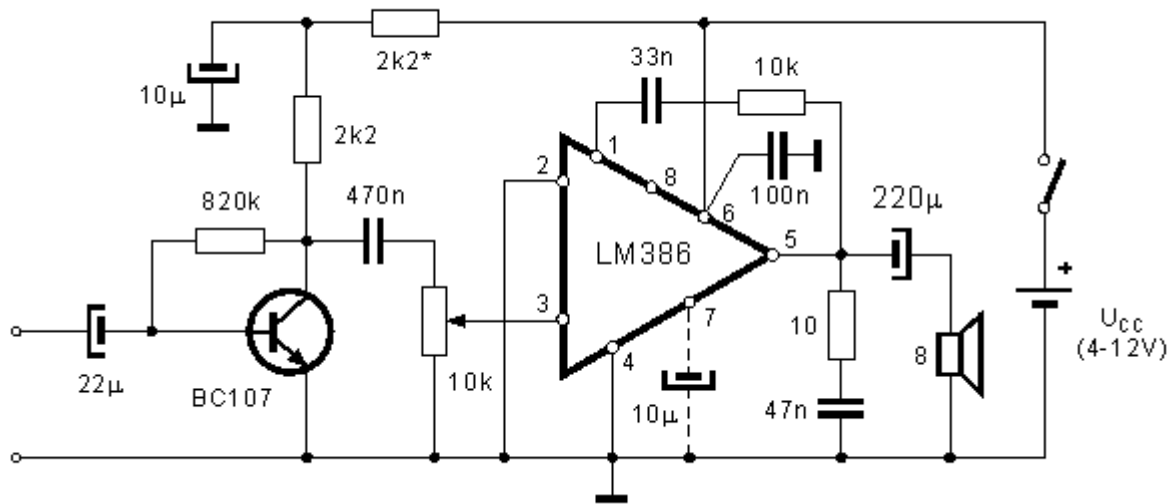


Fig. 7.7: complete audio-amplifier using the LM386

The third example is a simple alarm, shown in figure 7.8. It uses a CD4011 IC. Gates NI3 and NI4 form a 600Hz audio oscillator. This signal is amplified using an NPN transistor and passed to an 8R speaker. To hear the 600Hz tone, remove the connection to pin 8 and connect pin 8 to pin 9. This produces a constant tone. Gates NI1 and NI2 form a 4Hz oscillator, whose output is connected to pin 8. This turns the 600Hz tone on and off at 4Hz. To use this alarm in your home, on doors for example, connected pin 1 to 7 via a switch.

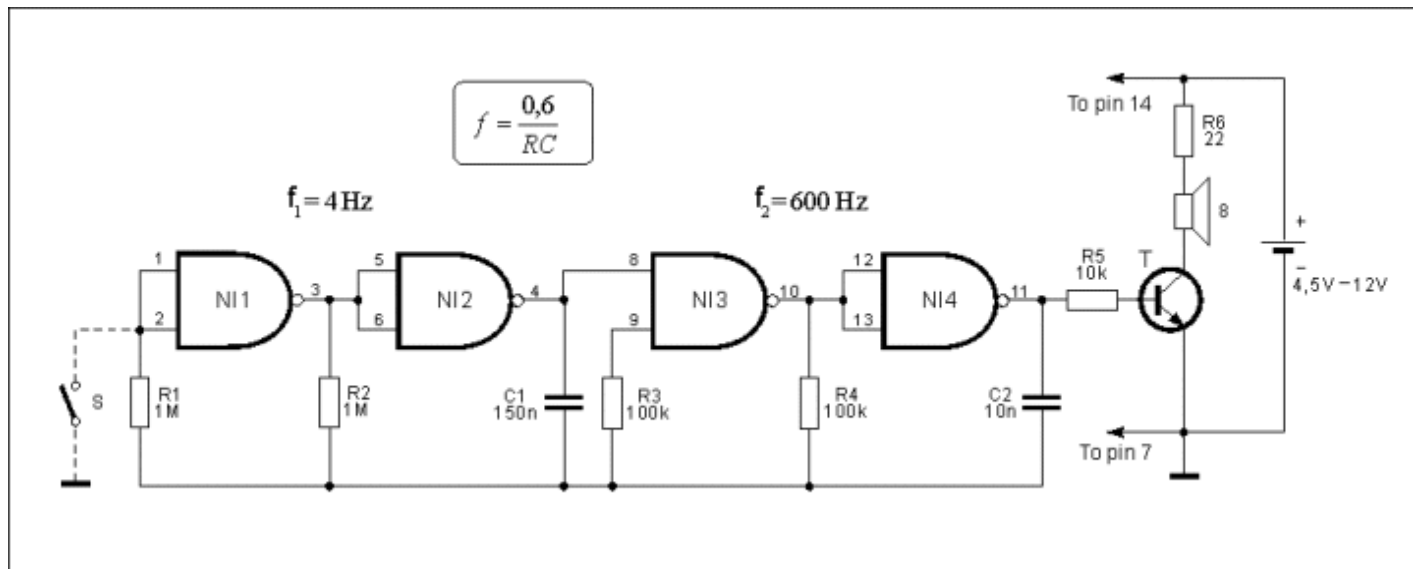
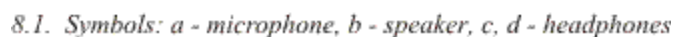


Fig. 7.8: Alarm using a CD4011 IC

The last circuit in this chapter is an example of a mono FM receiver using a TDA7088T IC, which can be, along with the SMD components, housed in a match-box along with two miniature watch batteries. You can purchase a ready-built scanning radio in a "junk shop" for as little as

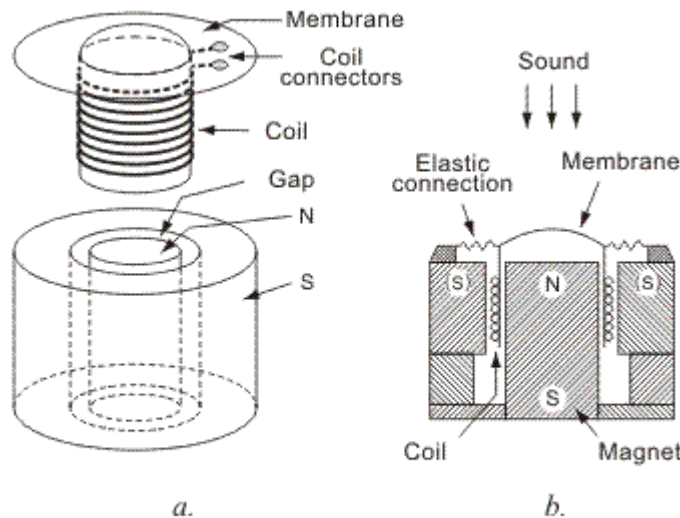
Tuning to a low frequency station is done automatically by pressing the RUN button. This turns on the part of the integrated circuit which is designated for scanning over a given range. When it finds a station it locks on until the RUN button is pressed again. When it reaches 108MHz it waits for the RESET signal which returns the scan to 88MHz.

Microphones, speakers and headphones are components commonly used as the input and output devices of many circuits. A microphone converts sound waves into electrical signals that closely follow the waveform of the sound being received. This signal is then amplified by the circuit and transformed into a sound by a speaker or headphone. The symbols for these components are shown on 8.1.



8.1 Microphones

There are several different types of microphone: carbon, dynamic, crystal, capacitive (electret). Carbon microphones were one of the first to be invented and were used mainly in telephone applications. But they are very noisy as the carbon granules rattle when the microphone is moved and this type is being replaced by more advanced types.



Sl. 8.2. Dynamic microphone: a - internal structure, b - cross section

Dynamic microphones are in wide use and their quality of reproduction is superb. They are used in the recording industry for music and speech where high fidelity is required. Basically they are exactly the same as a speaker, the only difference being the size. But their only limitation is the very low output. The internal structure is shown in figure 8.2. A paper cylinder, onto which fine copper wire is wound, is connected to a membrane which moves under the force of sound pressure created by the sound source. This coil is in a narrow gap with a high magnetic field created by a permanent magnet. When the coil moves in this magnetic field, it produces a voltage identical to the sound

causing the movement.

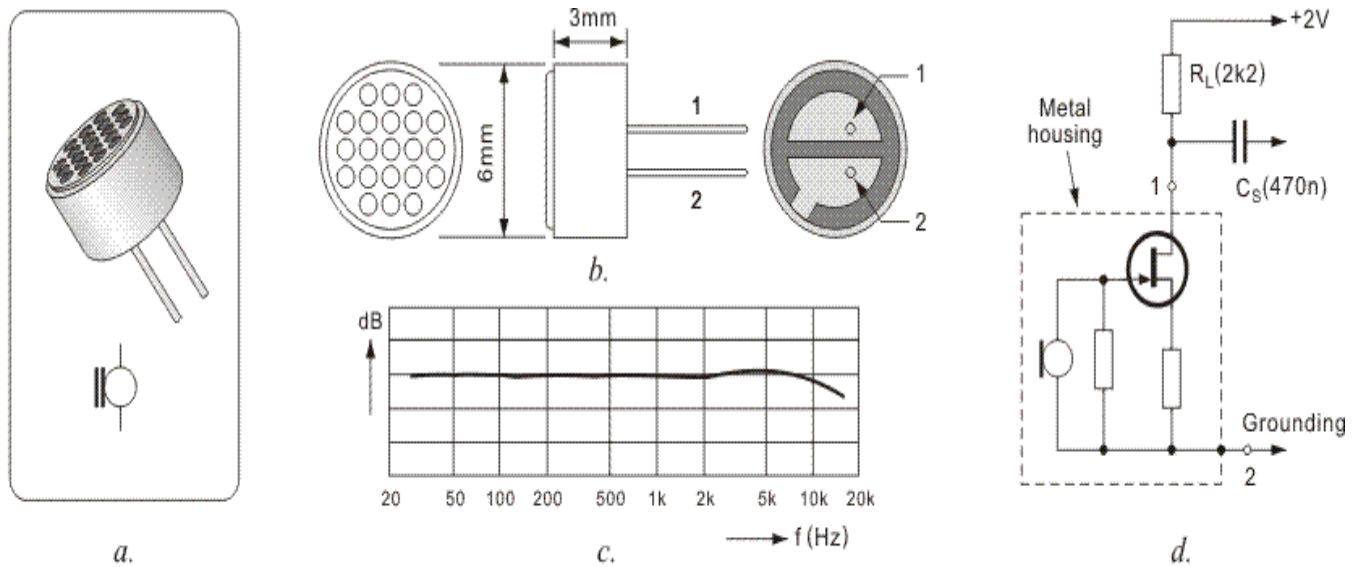
Because of the low resistance (impedance) of a dynamic microphone, it usually needs a transformer so it can be connected to an amplifier (called a pre-amp). This transformer is usually built into the microphone's case, but if is absent, it is necessary to connect the microphone to a preamplifier with low input resistance.

Crystal microphones contain a crystal called a "piezo crystal" that is connected to a small diaphragm. When sound waves hit the diaphragm, the crystal changes shape and it produces a voltage. This voltage is passed to an amplifier.

Recently, electret microphones have improved in quality and taken over from nearly all other types of microphone. They are small, rugged, low in price and produce a very high quality output.

The shape, size and characteristics are shown in 8.3.

The microphone contains a Field Effect Transistor, which means it needs a DC voltage for it to operate. Figure 8.3d shows how an electret mic is connected to a circuit. It needs a "load resistor" to limit the current to the FET and the output is taken across this resistor. That's the technical way of saying the output is taken from the point where the resistor meets the FET.

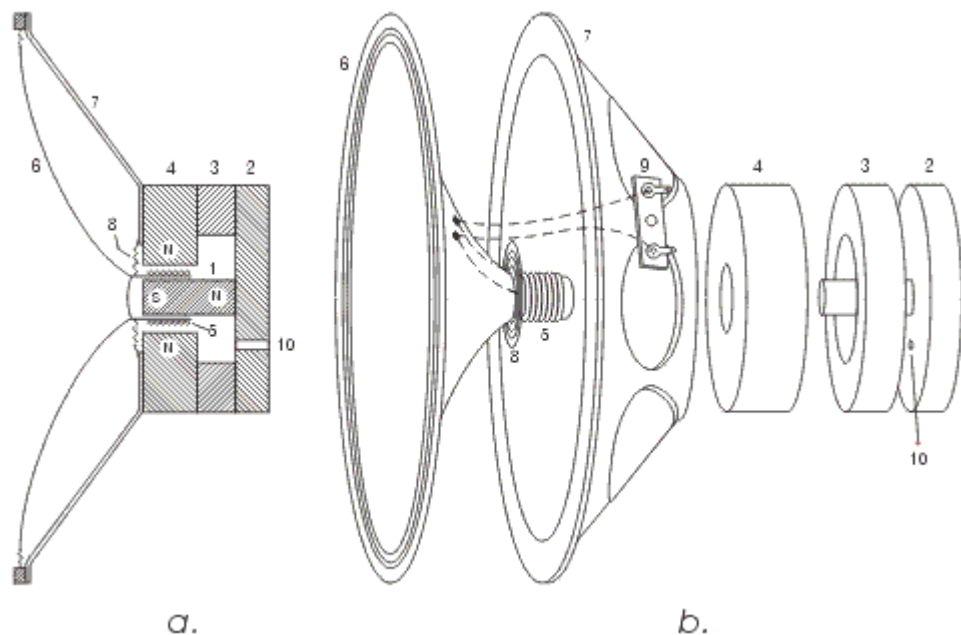


8.3. Electret microphone: a - picture and schematic symbol, b - size and connectors, c - frequency characteristics, d - connection

8.2 Speakers

Speakers vary enormously in size and shape. They can be designed as crystal or capacitive, but most often they are dynamic (called electro-dynamic construction).

The cross-section of an electro-dynamic speaker is shown in 8.4. Ferrite rings (2, 3 and 4) are added to a large permanent magnet (1) which creates a strong magnetic field in the narrow gap between magnets North and South poles. A Cylindrical former is added to the gap and it holds coil (5). The ends of the coil are taken to the outside of the speaker.

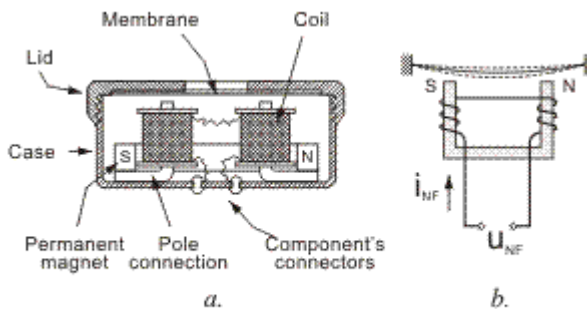


The two most important characteristics of a speaker are its resistance (we actually call the resistance of a speaker IMPEDANCE as the value is determined at a frequency of 1kHz and the value is higher than its actual resistance) and its wattage. Common impedances are 4, 8 and 16

ohm, but there are also 1.5, 40 and 80 ohm speakers. Speaker wattages range from a fraction of a watt to hundreds of watts.

When choosing a speaker, it is advisable to choose the largest speaker possible as they are more efficient and produce the least distortion especially in the low frequency range. Speakers should be housed in a large box since it functions as a resonating chamber and this greatly adds to the overall quality of the sound.

8.3 Headphones



8.5. Elektromagnetic headphone:

There are several types of headphone: crystal and electromagnetic. The electromagnetic type is the most commonly used. They functioning in the same way as speakers, with obvious differences in construction, since they are intended for much lower power. Their main characteristic is their resistance (impedance), from a few ohms to a few thousand ohms.

The cross section of an electromagnetic headphone is shown in 8.5. It consists of a horseshoe magnet with poles that hold two coils. These are connected in series. The diaphragm is a thin steel plate. When current flows through the coils, the diaphragm is pulled towards the coils. This moves the air and the result is heard as a faithful reproduction.

8.4 Examples

The schematic of a very simple FM radio-transmitter is shown in figure 8.6. It uses an electret microphone and transmits on a frequency between 88MHz and 108MHz.

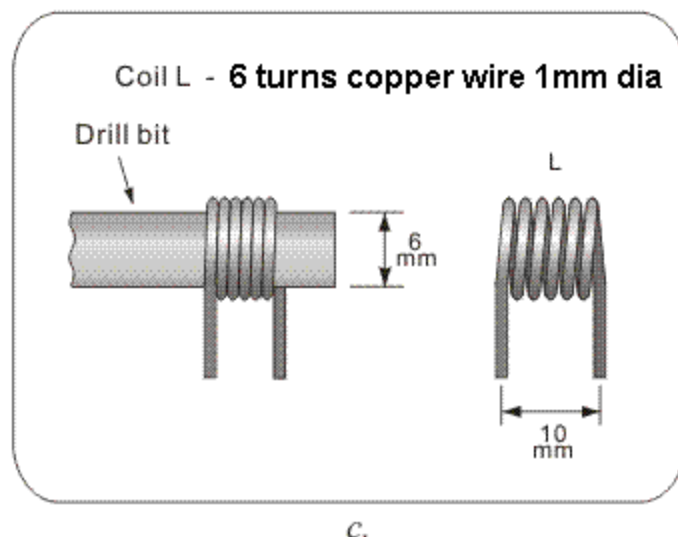
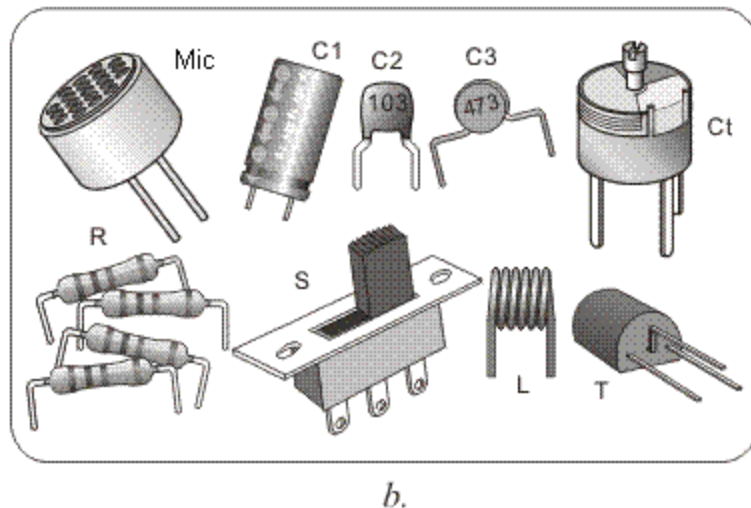
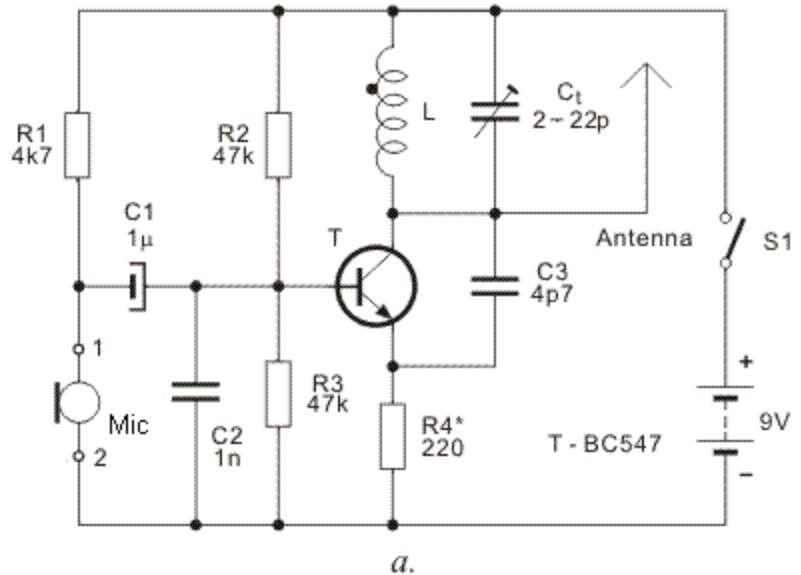
The transistor, coil L, trimmer capacitor C_t , capacitor C_3 and resistors R_2 , R_3 and R_4 creates an oscillator with a frequency determined by:

$$f_o = \frac{1}{2\pi\sqrt{L(C_t + C_{CB})}}$$

In this equation C_{CB} represents the capacitance between the collector and the base. The value of this capacitance depends on the voltage on the base. The higher the voltage, the lower the capacitance and vice versa. The voltage on the base is constant while there is no sound, which means the frequency of the oscillator is constant. When the microphone picks up a sound, it is passed to the base of the transistor via C_1 . This causes the frequency of the oscillator to change and that's why the circuit is called FREQUENCY MODULATED (FM).

To transmit on a frequency away from any other radio station, a trim cap is included. The transmitter has a range up to 200 metres, depending on the length of the antenna and where it is placed. Ideally, the antenna should be vertical and as high as possible.

The antenna can be as long as 3 metres but 180cm will work very well.

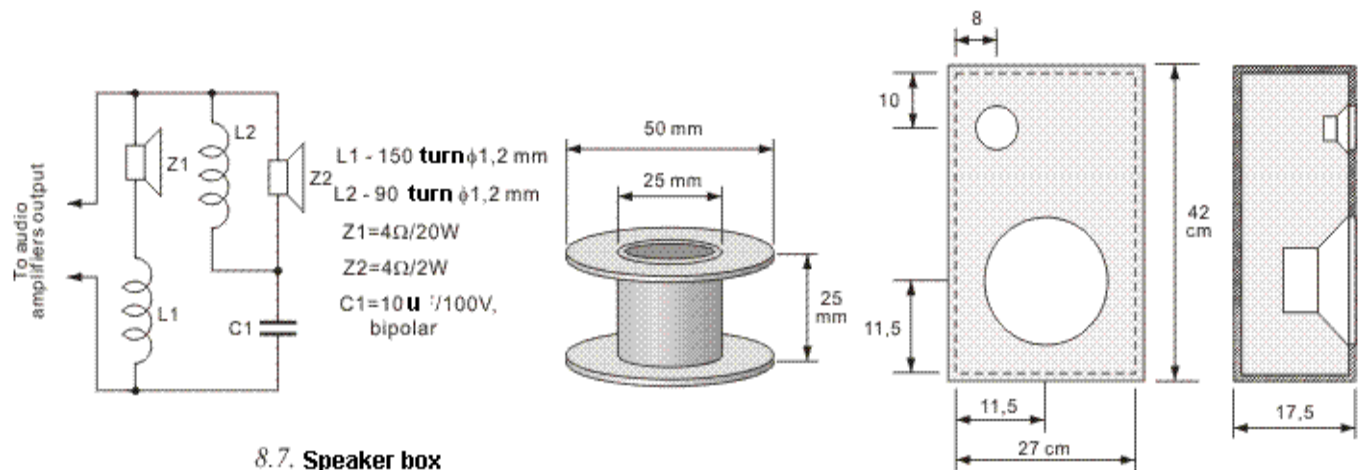


Sl. 8.6. Simple FM radio transmitter:
a - schematic, b - components, c - making the coil

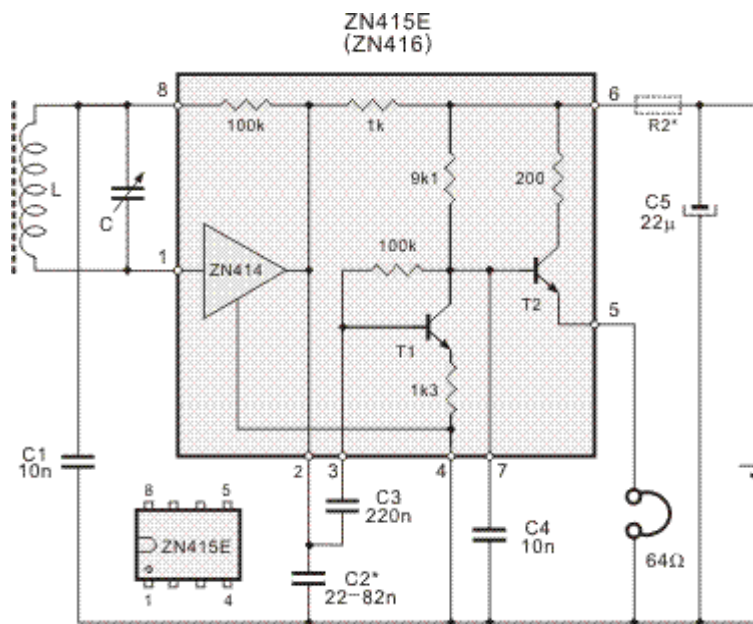
Coil L is made by winding 6 turns of 1mm enameled wire on a 6mm dia drill bit. This coil can be stretched or squashed to adjust the operating frequency of the circuit and the trimmer will fine tune the frequency.

High Fidelity (or Hi-Fi) sound reproduction is the main purpose for using good-quality speakers. They are used in radios, TV's, cassette players, CD players, etc. The speakers are housed in speaker boxes and use at least two speakers. This is because no individual speaker is capable of reproducing the full range of frequencies. A speaker with a large cone is called a "Woofers" and will reproduce the low frequencies. A speaker with a small cone is called a "tweeter" and will reproduce the high frequencies. Together, they will reproduce the full range of between 30Hz and 15kHz.

The difficulty is now to detect the low or high frequency and divert the correct frequency to the particular speaker. This is the job of a cross-over network. In the figure 8.7 an inductor L1 passes the low frequencies to speaker Z1 and capacitor C1 passes the high frequencies to speaker Z2. Z1 reproduces frequencies from 30Hz to 800Hz and Z2 reproduces sounds with frequencies from 800Hz to 15kHz.



8.7. Speaker box



8.8. Mini AM radio-receiver using the ZN415E

Headphones are most commonly used with portable devices, such as radio receivers, cassette players, CD walkmans, mp3 players, etc. Headphones produce a very high quality reproduction. All modern devices have an audio-amplifier. It usually employs an integrated circuit and most of these are designed for 32 ohm headphones. There are also 8 ohm and 16 ohm headphones.

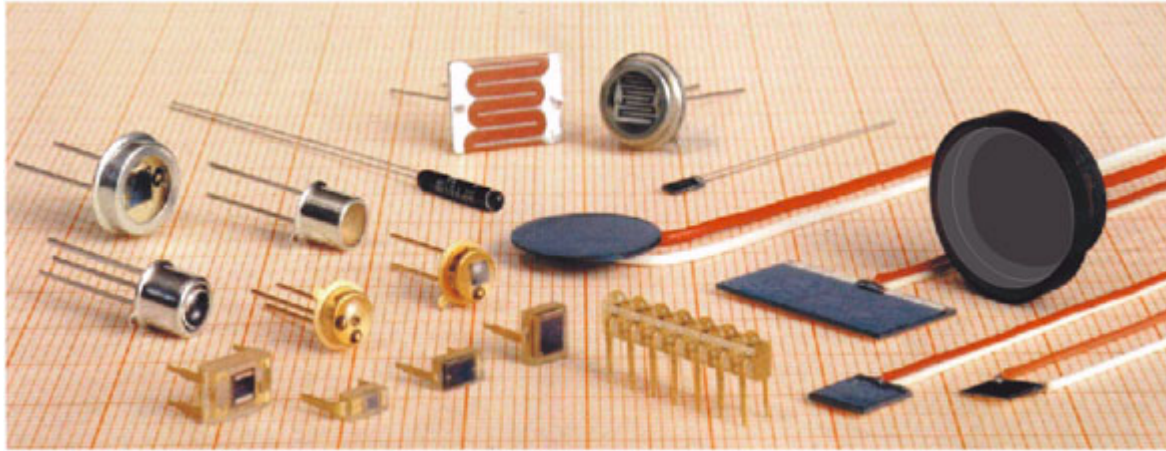
The schematic of a AM portable radio is shown in figure 8.8. It's built around the ZN416 integrated circuit. The output is connected to two serially connected 32 ohm headphones, with overall resistance of 64 ohms.

It is possible to connect the radio receiver in figure 8.8 to amplifier in figure 7.3 to produce a radio with speaker output.

9. Opto-electronic components

Optoelectronic components (or as often referred to photo-electronic components), are electronic components which produce light or react to it. Some components among them are LEDs (Light

Emitting Diodes), photo transistors, photo diodes, photo resistors (or LDR – Light Dependant Resistors), different visual indicators, light emitters and detectors, optocouplers, etc. Many of those components can be easily recognized because of the “window” on the component's case which is used to pass the light. Sometimes, instead of a window, there is a small lens, which directs light to some predestined location inside of the component. Some of the most important optoelectronic components are shown on photo 9.1.

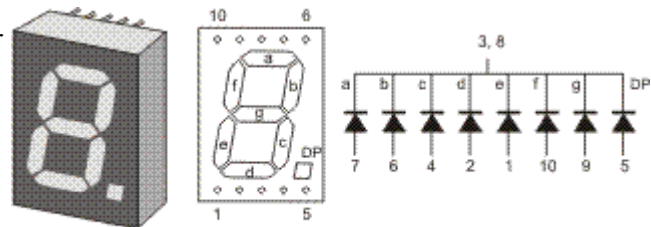


9.1 Photo-electronic components

We already mentioned the most frequently used component of them – the LED. Basic role of a LED in circuits is a visual indicator of, for example, state of the device (on/off), but is not rare in other indicator appliances, voltage stabilizers, etc. There is an abundance of colors, shapes and sizes to choose from, but most frequent ones are red, green and yellow. Because of the different and more complicated manufacturing process, blue ones cost a bit more than other ones. There are square, housed, SMD, angled, ultra bright, multicolored and many other kinds, but they all have the same principles of use.

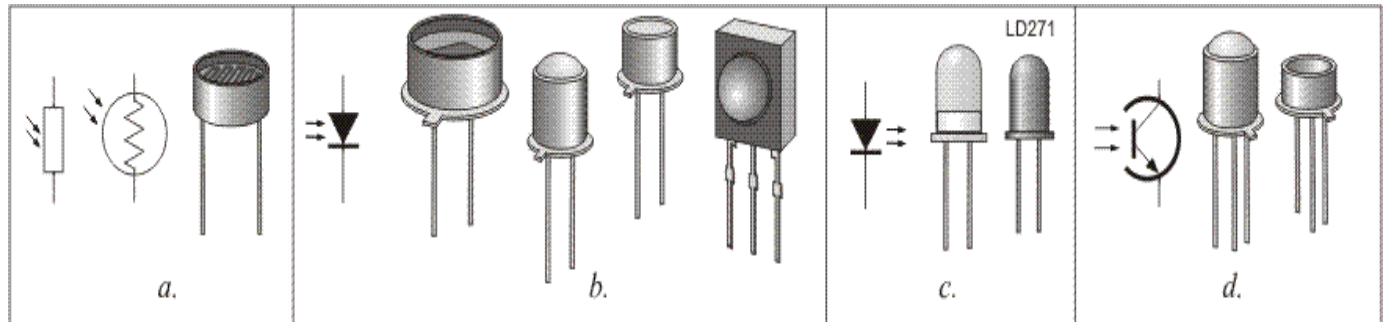
Another application of LEDs is a LED display.

One display is on 9.2. It is, as shown, facilitated out of 8 diodes marked with an a,b,c,d,e,f,g and DP (DP being the Decimal Point). These devices come in two possible flavors – with a common cathode (as this display), or with a common anode. In both cases it is necessary to connect protection resistors to all diodes (which is the same as when working with ordinary LEDs).



9.2 LED display

Photo diodes are similar to other, ordinary, diodes internally. One main difference is in that that photo diode has an exposed surface to for light to fall onto. These diodes are acting as high value resistor while in dark. It's resistance lowers as light gains in intensity. In their behavior they are similar to photo resistors, apart from that as with all diodes polarity of the component must be appropriately positioned.



9.3. Opto-electronic components: a - resistors, b - detecting (receiving) diodes, c - emitting (transmitter) diodes, d - transistors

Emitting diodes are special kind of photo-diodes. One of them is the LED, and some of them include infra-red or ultra-violet emitting for different wireless communication purposes. Most common area of application of IR-LEDs (Infra Red) are remote controllers for TVs and other devices.

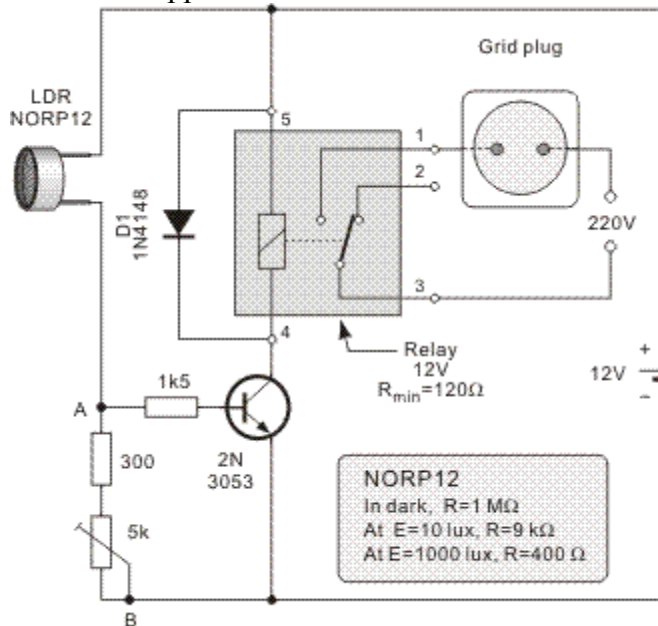
Photo diodes are usually housed in round metallic or square plastic cases with a glass window or a lens which focuses the incoming light.

Photo-transistor's internal parts are similar to internals of a regular transistor. One main difference between them is the glass window which allows light to reach the crystal plate which holds all transistor's parts. With changes of light intensity, resistance between base and the collector varies, and this influences variations of the collector current. In this component light has the same role as voltage over base of the regular transistor. When intensity rises, current through the transistor rises as well, and other way round, if intensity fades, current fades.

Photo electronic components are manufactured in an array of different case shapes and sizes. Several of them, together with their schematics symbols are displayed on 9.3.

One special group of photo-electronic components are the optocouplers. These are special integrated circuits facilitated out of an IR photo diode, and some component which is sensitive to light (photo transistor, photo thyristor). Diode is called an emitter, and "receiving" end is called the detector. This means that the only connection between the emitter and detector is through a ray of light. This is an important property of optocouplers, since it allows two different parts of the circuit which operate on different supply voltages to connect to each other without actually conducting electricity, which means that one part could operate on 9V and other on 5V without fear of burning the sensitive lower voltage components.

the wanted appliance to the mains.



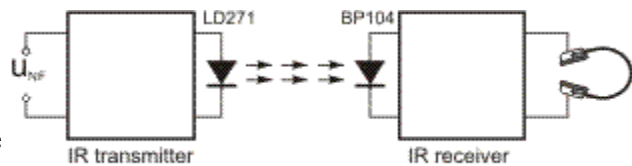
9.5. Optic relay

than 120 Ohm. Current rate through the relay should be equal to or greater than needed by the device plugged to mains. If, for example, we were looking at an 1kW electric heater, it's current is equal to:

$$I = P/U = 1000W/220V = 4,5 \text{ A.}$$

Any TUN transistor whose maximum current rating is higher than current through relay's rate, is alright. This value is calculated by dividing battery voltage with relay's coil resistance. When we want to employ remote control over some device, it is possible to utilize different technologies, but in some cases cable connection or radio wave control aren't the most appropriate ones, like the one between the TV and it's remote controller. Some IR emitting and receiving photo diodes are used specifically in low range transmitters and receivers. Block scheme on 9.6 represents usage of photo diodes between the sound source (hi-fi, radio receiver, TV) and headphones, which removes the need for long cables.

Low frequency signal which is to be carried is marked with uLF. Based on that frequency, IR transmitter modulates the HF voltage, called the carrier. This modulated HF voltage is further sent to emitting diode LD271. Variable light emitted by this diode varies resistance of the receiving diode, and thus the HF signal created using this variations is equal to the modulated signal on the transceivers end. IR receiver is demodulating this signal, which transforms the received HF signal into the original LF signal which is equal to the original sound. This signal is further amplified and brought to headphones. Using optical components enables safe interfacing of different devices to your home PC. There is a schematic on 9.7 which displays a simple way to interface a random device to the parallel (printer) port of the computer. For simplicity we chose to connect small portable radio receiver



9.6. Radio transmission using the infrared light

Slider of the 5k Ohm trimmer resistor sets sensitivity of entire circuit. Lower the slider's position to lower the light level that triggers the appliance on. Greatest sensitivity is reached when trimmer is omitted from the circuit.

There is a possibility to use a photo-diode instead of a LDR (cathode goes up, to + of the battery), or a photo-transistor (collector up).

The device would be turned off when light is absent in case we placed 47k Ohm regular resistor instead, and LDR between points A and B.

Each relay has a coil which accords to voltage of the battery. In our case that is 12V. Resistance of the coil is several hundreds of Ohms, and it shouldn't be lower

supplied using a 9V battery.

Receiver, battery and the interface circuit are connected to the parallel port using the male SUB-D 25 connector. Program which is to control the circuit is easily developed in any programming language. We display a sample program written in Q-Basic, it will turn the receiver in 7am and turn it off in 7:30 am.

REM Wake up program

10 DO

20 LOOP UNTIL TIMES\$="07:00:00"

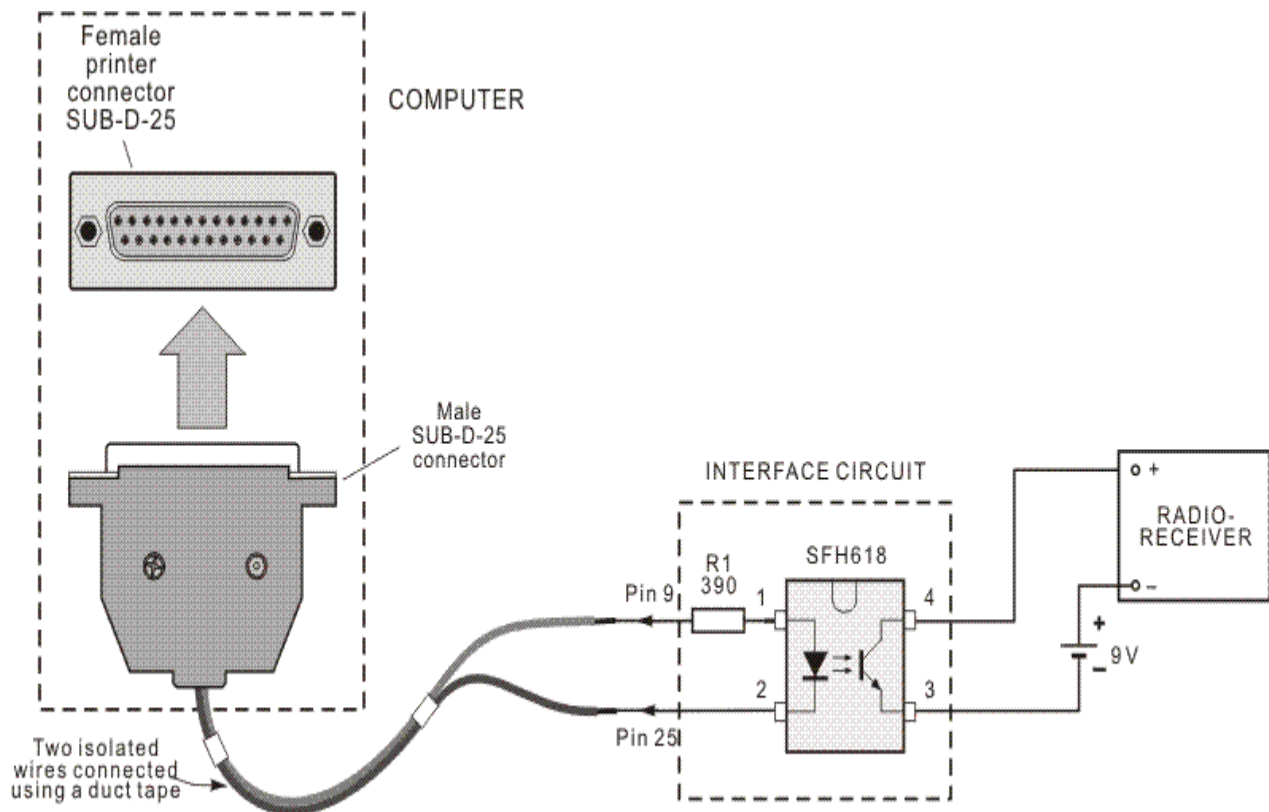
30 OUT &H378, 128

40 SLEEP 900

50 OUT &H378, 0

60 STOP

At 7 o'clock, voltage on pin 9 will turn to +5V, and it will remain that way for the next 900seconds.



9.7. Controlling the radio receiver using a computer

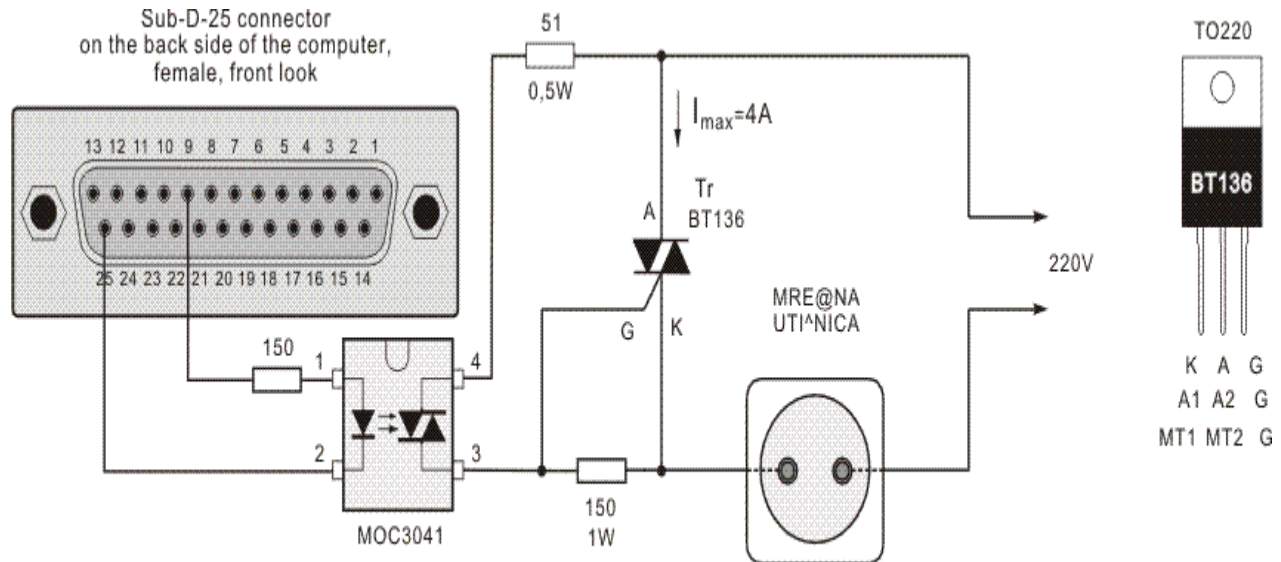
A bit more modern operating systems than Windows 95 will have different ways of controlling the parallel port, and there is an extensive knowledge base on the Internet for programming this kind of operation on any operating system. Google is your friend!

Schematic of another interface circuit on 9.8 enables connection of any device plugged to the mains grid to be turned on or off. Control over this device is done in the same fashion as done in

previous program.

When, according to the program pin 9 is +5V (logic one), diode will conduct electricity. Light emitted by it switches the triac inside of the optocoupler on. This current flows through the 150Ohm resistor and creates a voltage drop which ignites the triac, which enables current flow from the mains, which powers the device.

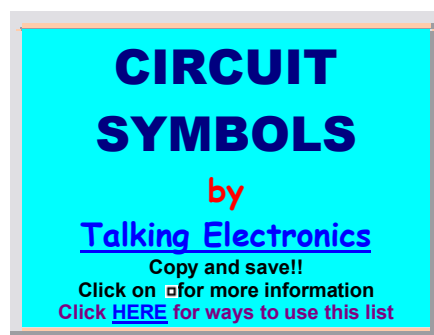
Maximum allowed current of the BT136 triac is 4A, which means that maximum allowed power of the device is 990W. It is worth saying that optocouplers should be used only with resistance load devices (light bulbs, heaters...). When connecting inductance load devices like electro motors, transformers and such, it is advised to use the relay interfaces.
















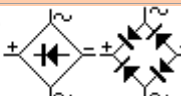







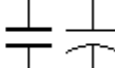
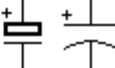




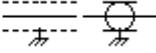








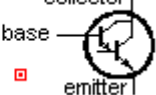

9.8. Interface using an opto-coupler and triac

10. Other components

The following table covers almost every circuit symbol you will need. This is the English/American version of each symbol. The European version of some symbols is slightly different and are shown further down the page.



ALTERNISTOR TRIAC	Main Terminal1	
A TRIAC and 33 - 43v DIAC	Gate	
	Main Terminal 2	
Ammeter (amp meter)		
AND Gate		
AND Gate		
Antenna balanced		
Antenna Loop, Shielded		
Antenna Loop, Unshielded		
Antenna unbalanced		
Attenuator, fixed (see Resistor)		
Attenuator, variable (see Resistor)		
Battery		
Bilateral Switch (DIAC)		
Bridge Rectifier (Diode Bridge)		
BUFFER (Amplifier Gate)		
BUFFER (Amplifier Gate)		
Buzzer		

Capacitor feedthrough	
Capacitor non-polarised	
Capacitor polarised (see electrolytic)	
Capacitor Variable	
Cavity Resonator	
Cell	
Circuit Breaker	
Coaxial Cable	
Connectors	
Plug (male)	
Jack (female)	
connected	
Plug (male)	
(female)	
CRO – Cathode Ray Oscilloscope	
Crystal Microphone (Piezoelectric)	
Crystal Piezoelectric	
Darlington Transistor	
Delay Line	

DIAC
(Bilateral Switch)



Diode



Diode - Gunn



Diode - Light Emitting
(LED)



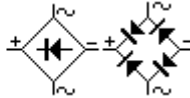
Diode
Photo Sensitive



Diode
Photovoltaic



Diode Bridge
(Bridge Rectifier)



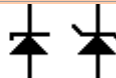
Diode - Pin



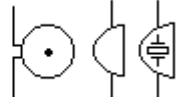
Diode - Varactor



Diode - Zener



Earpiece
(earphone,
crystal earpiece)



Electroluminescence



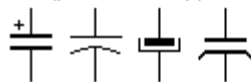
Electret Microphone
(Condenser mic)



Electrolytic
(Polarised Capacitor)



alternate symbols:
(positive on top)



Electrolytic - Tantalum

positive end
black band or
chamfer



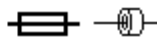
Exclusive-OR Gate
(XOR Gate)



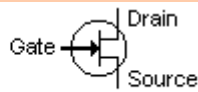
Exclusive-OR Gate
(XOR Gate)



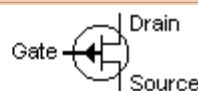
Ferrite Bead



Field Effect
Transistor
(FET) n-channel
also: N-Channel J FET



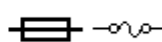
Field Effect
Transistor
(FET) p-channel
also: P-Channel J FET



Flashing LED
(Light Emitting Diode)
(Indicates chip inside LED)



Fuse



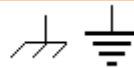
Galvanometer



Globe



Ground
Chassis



Ground
Earth



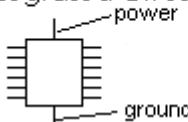
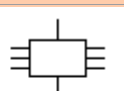
Headphone



Heater



IC
Integrated Circuit


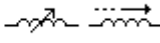




















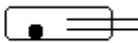
Inductor
Air Core




Inductor
Iron Core
or
ferrite core




Inductor Tapped	
Inductor Variable	
Integrated Circuit	
Inverter (NOT Gate)	
INVERTER (NOT Gate)	
Jack Co-axial	
Jack Phone (Phone Jack)	
Jack Phone (Switched)	
Jack Phone (3 conductor)	
Key Telegraph (Morse Key)	
Lamp Incandescent	
Lamp - Neon	
LASCR (Light Activated Silicon Controlled Rectifier)	
LASER diode  laser diode photo diode	
LDR (Light Dependent Resistor)	
Light Emitting Diode (LED) 	
Light Emitting Diode (LED - flashing)  (Indicates chip inside LED)	

Mercury Switch 

Micro-amp meter
(micro-ammeter) 


Microphone
(see Electret Mic) 

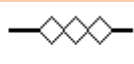
Microphone
(Crystal - piezoelectric) 


Milliamp meter
(milli-ammeter) 

Motor 

NAND Gate 


NAND Gate 


Nitinol wire
"Muscle wire" 

Negative Voltage
Connection 


NOR Gate 

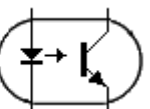
NOR Gate 

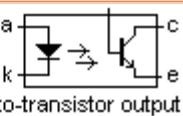
NOT Gate
Inverter 

NOT Gate
Inverter 

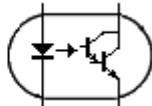
Ohm meter 

Operational Amplifier
(Op Amp) 

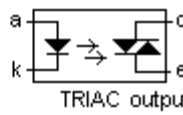
Optocoupler
(Transistor output) 

Opto Coupler
(Opto-isolator) 
Photo-transistor output

Optocoupler
(Darlington output)



Opto Coupler
(Opto-isolator)



OR Gate



OR Gate



Oscilloscope
see CRO



Outlet
(Power Outlet)



Piezo Diaphragm



Photo Cell
(photo sensitive resistor)

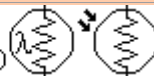


Photo Darlington
Transistor



Photo Diode

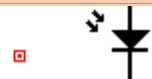


Photo FET
(Field Effect Transistor)

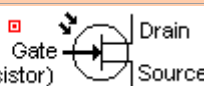
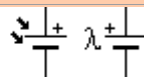


Photo Transistor



Photovoltaic Cell
(Solar Cell)



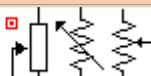
Piezo Tweeter
(Piezo Speaker)



Positive Voltage
Connection



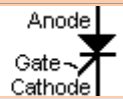
Potentiometer
(variable resistor)



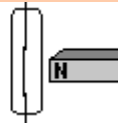
Rectifier
Semiconductor



Rectifier
Silicon Controlled
(SCR)



Reed Switch



Relay - spst



Relay - spdt



Relay - dpst



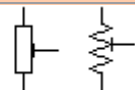
Relay - dpdt



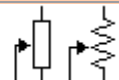
Resistor
Fixed



Resistor
preset



Resistor
variable



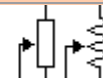
Resonator
3-pin



RFC
Radio Frequency Choke



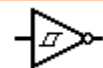
Rheostat
(Variable Resistor)



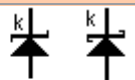
Saturable Reactor



Schmitt Trigger
(Inverter Gate)



Schottky Diode
(also Schottky)

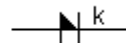


Low forward voltage 0.3v
Fast switching
also called Schottky Barrier Diode

Shielding



Shockley Diode



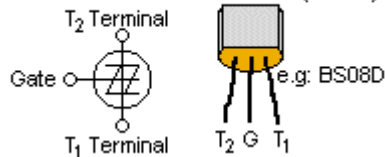
4-layer PNP device

Remains off until forward current reaches the forward break-over voltage.

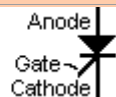
Signal Generator



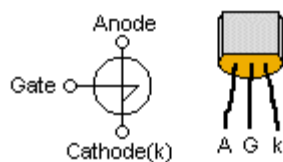
Silicon Bilateral Switch (SBS)



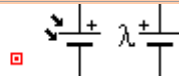
Silicon Controlled Rectifier (SCR)



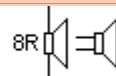
Silicon Unilateral Switch (SUS)



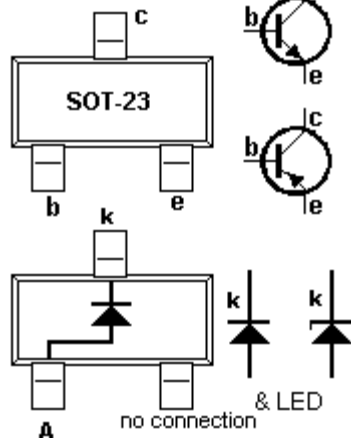
Solar Cell



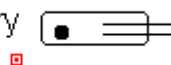
Speaker



Surface Mount



Switch - mercury
tilt switch



Switch - spst



Switch - spdt



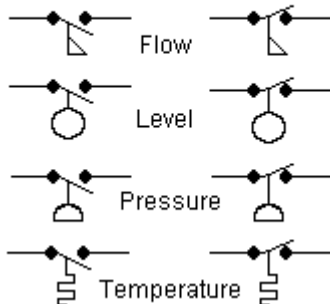
Switch - dpst



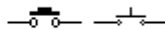
Switch - dpdt



Switch - process activated
normally open: normally closed:



Switch - push
(Push Button)



Switch - push off
(used in alarms etc)



Switch - Rotary

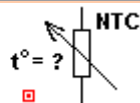


Test Point

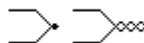


Thermal Probe

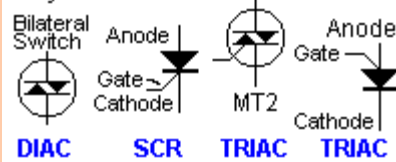
NTC: as temp rises,
resistance decreases



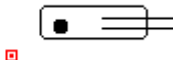
Thermocouple



Thyristors: Main Terminal1



Tilt switch
mercury



Touch Sensor



Transformer
Air Core



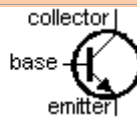
Transformer
Iron Core



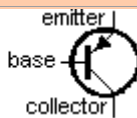
Transformer
(Tapped Primary/Sec)



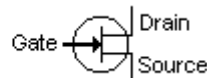
Transistor
Bipolar - NPN



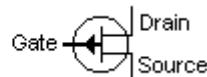
Transistor
Bipolar - PNP



Transistor
n-channel
Field Effect



Transistor
p-channel
Field Effect



Transistor Metal Oxide
Single Gate



Transistor Metal Oxide
Dual Gate



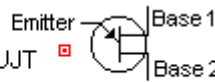
Transistor
Photosensitive



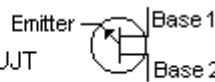
Transistor
Schottky - NPN



Transistor
Unijunction - UJT
Unijunction Transistor (UJT) N-type



Transistor
Unijunction - UJT
Unijunction Transistor (UJT) P-type



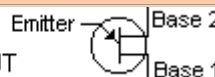
TRIAC
Main Terminal1
MT2
Anode
Gate
Cathode



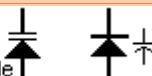
Tunnel Diode

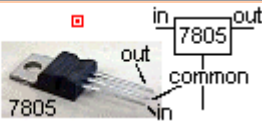

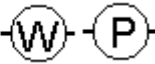


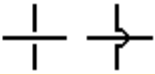


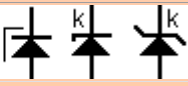


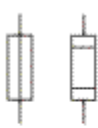
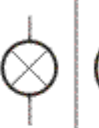


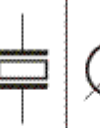
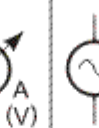


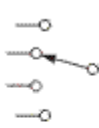


Unijunction
Transistor - UJT



Varactor
varactor diode



Voltage Regulator (7805 etc)	
Voltmeter	
Wattmeter	
Wires	
Wires Connected	
Wires Not Connected	
XOR Gate (exclusive OR)	
XOR Gate (exclusive OR)	
Zener Diode	
Learn BASIC ELECTRONICS Go to: Talking Electronics email Colin Mitchell 12-8-2007	

										
<i>a.</i>	<i>b.</i>	<i>c.</i>	<i>d.</i>	<i>e.</i>	<i>f.</i>	<i>g.</i>	<i>h.</i>	<i>i.</i>	<i>j.</i>	<i>k.</i>
fuse	lamp	neon lamp	VDR resistor	cell	quartz crystal	ammeter or voltmeter	AC voltage	switch	double pole switch	4 position switch

10.1.

NOTES

Here are a few notes on the symbols above.

Fuses (10.1a) have single role in a circuit - to detect excess current and protect the device. In most cases the excess current flows when a higher voltage is present but a fuse cannot detect the voltage - it can only detect when a higher current flows. The higher voltage causes the higher current to flow and this triggers the action of "blowing the fuse." Of course, when a component fails, a higher current can flow and this will also "blow the fuse."

Fuses come in all sizes and ratings (current flow) and it is important to know that the size of the wire inside a fuse does not necessarily indicate the current rating.

The wire inside can be made from copper and plated to protect it from oxidizing or it can be a low temperature material that needs to be a larger diameter.

The wire can also be wound in a spiral and formed into a spring. The end of the spring sits in a blob of solder and when the spring heats up, the solder melts and the spring separates from the other end.

This is called a DELAY FUSE.

Other forms of delay fuse consist of a wire joined at the centre by a blob of solder and others are made of low-temperature-melting material.

Some pieces of equipment use expensive fuses and whenever a fuse is damaged, you must decide if the problem is a major or minor fault.

Sometimes a fuse can go open-circuit for no apparent reason. It can "wear-out."

For instance, some equipment takes a very high current when it is turned on and you will see the fuse heat up and stretch and dip in the middle. This causes strain on the fuse and eventually the wire oxidizes to a point where it finally "burns out."

The equipment is not faulty and it is just a matter of replacing the fuse.

Sometimes the fuse completely explodes and the glass is thrown all over the chassis. This indicates a short-circuit in the power supply and most often one or more of the diodes must be replaced.

The fuse can also go off with a "bang" and the inside of the glass is coated with "silver." This also indicates a diode is damaged in the power supply. Generally 2 or 4 diodes are damaged. If the fuse is damaged beyond recognition, you will not know if it is a delay fuse or a normal fuse.

The current-rating on the end-cap can sometimes help you.

For instance, if a fuse is rated at 4A, you will need to replace it with a 4 amp normal fuse or 3.15 amp slow-blow.

When fuses are rating at 100mA to 250mA, they are very delicate and will not accept the slightest overload.

When replacing this type of fuse, it is necessary to determine if the equipment is drawing a heavy current when turning on or if a fault exists in the power supply. Sometimes the switch can cause the problem if it is not making contact fast enough.

Replace the fuse and watch it as someone else turns on the equipment. If the fuse burns out immediately, a short exists. If the fuse glows red and burns out, the equipment is drawing too much current during turn-on. This may be due to devices you have added to the equipment or operation on a slightly higher voltage. You can try a fuse with a slightly higher rating to see if the fault is fixed.

Never replace a 100mA fuse with a 1 amp fuse. The 1 amp fuse will never "blow" and if the transformer is being overloaded, the transformer will simply "cook."

Lamps (10.1b) Ordinary electric light globes heat a coil of tungsten wire inside a glass bulb that

has an inert gas such as argon. The resistance of the filament depends on the temperature it is heated to. It can be ten to twenty times higher than when it is cold.

A neon lamp (10.1c) contains a gas (such as neon) and this gas gives off a glow when a high voltage is applied to two plates. This glow occurs at about 70v to 90v and a resistor must be used in series to prevent the voltage rising higher than required by the lamp. To put this more accurately, the resistance of the neon lamp reduces when it "strikes" and a high current will flow. To limit this current a "current limit" resistor is needed.

VDR (10.1d) The resistance of a VDR depends on the voltage across it. A VDR is also called a VARISTOR. Its resistance is high until a critical value of voltage and the resistance suddenly drops. They are used as voltage protection devices. If they, for example, see a voltage higher than 220V, their resistance decreases and this "soaks" the excess voltage. Their response time is only a few 10's of nanoseconds.

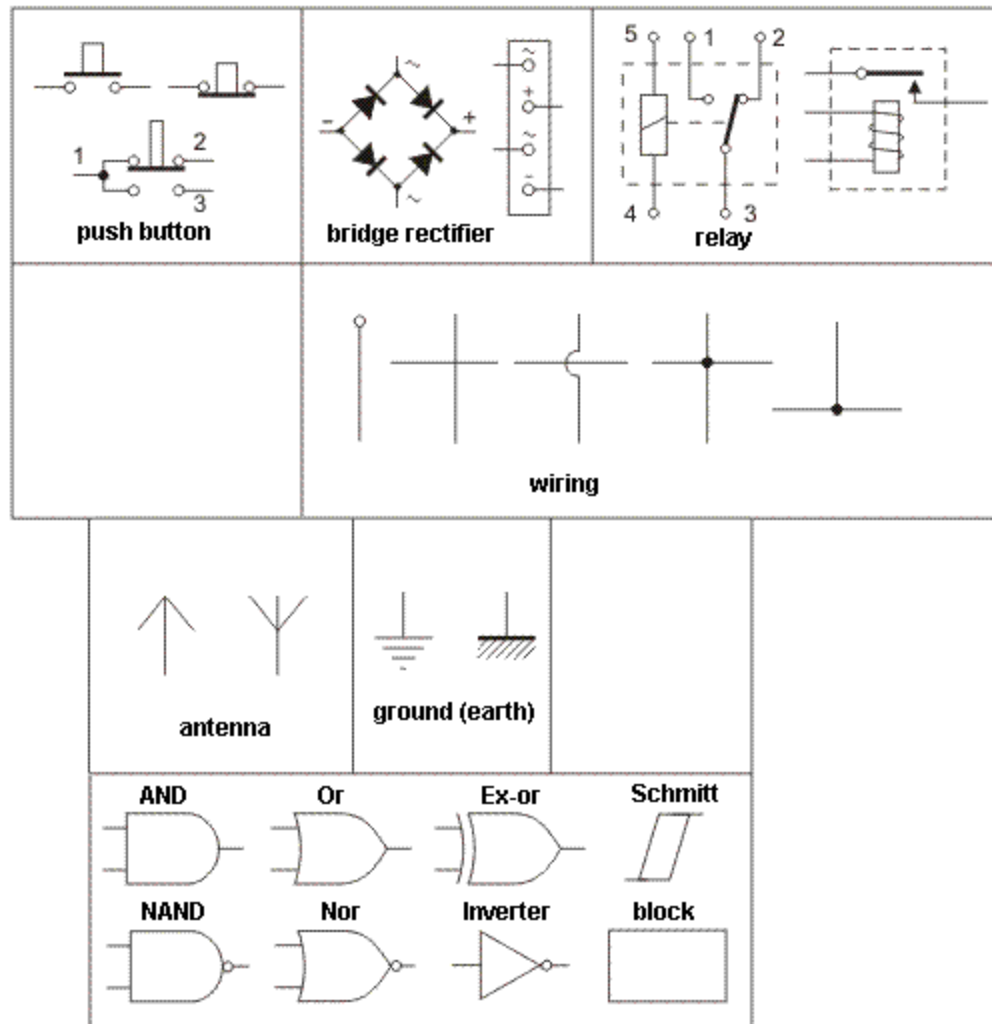
The symbol for a single DC cell is shown in 10.1e.

A Quartz crystal is shown in 10.1f. It is a thin sheet of quartz material between two metal plates and packaged in a metal case. Quartz crystals are commonly used as the reference for an oscillator circuit, such as a clock source in microprocessor designs.

An instrument for measuring current (A) and voltage (V) is shown in 10.1g. This symbol dates from the time when analog instruments with a needle were used. The symbol remains the same, although digital instruments have replaced analog devices.

AC voltage symbol is shown in 10.1h. The shape of the wave is shown in the symbol. It can be sine-wave or saw-tooth or square-wave.

The simplest form of switch device is displayed in 10.1i. Because of the wide range of switches, there are many different types in use. For example, a two pole switch (10.1j) has two operating positions, in one position it connects points 1 and 2, and in the other it connects points 1 and 3. There are switches with more operating positions. 10.1k is an example of a rotary switch with four positions.



Momentary switches, or push buttons have a built-in spring, which makes the switch conduct only while it is being pressed (your standard doorbell has this kind of switch).

Four diodes in a single case is called a BRIDGE. Two pins are marked with sine waves, used to connect to the AC voltage and two marked with "+" and "-"

RELAY When an electromagnet receives sufficient voltage on points 4 and 5, connection between points 2 and 3 is opened, and at the same time points 3 and 1 are closed. A relay is actually an electromagnetic switch.

Symbols for a receiving and transmitting antenna are shown.

Grounding symbols Grounding and common ground aren't the same thing, but if both exist in a circuit, they are always connected to each other. With electronic devices housed in a metal case, grounding is connected to the metal housing.

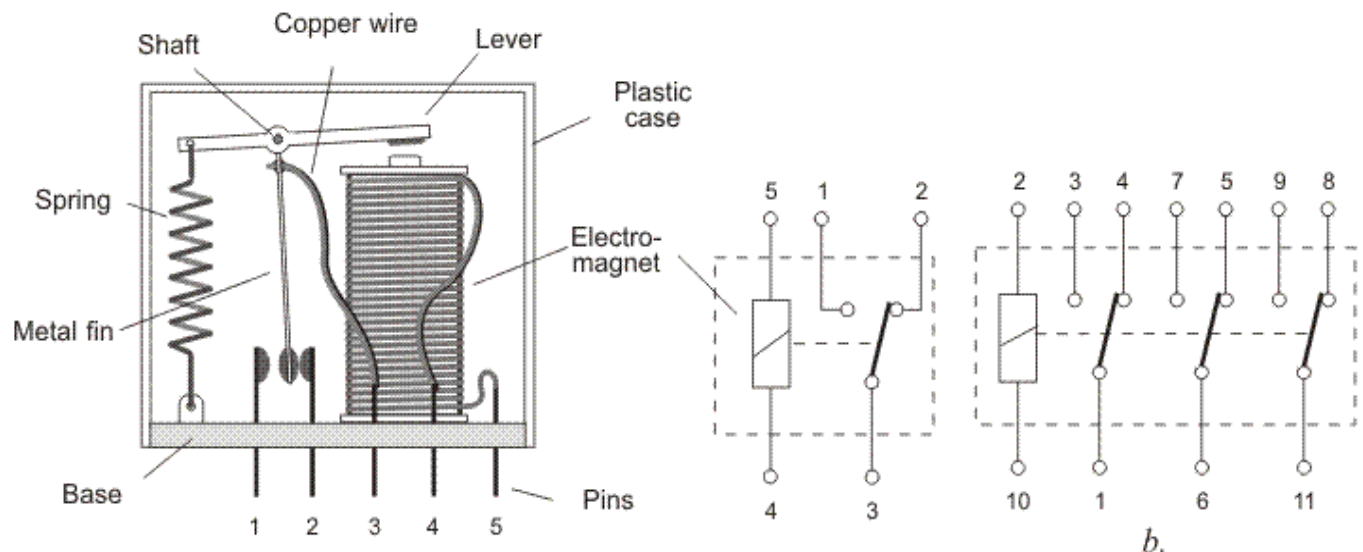
Schematic symbols representing logic gates and different digital integrated circuits are shown above. It should be kept in mind that basic logic gates (AND, OR, XOR, Inverter, etc.) aren't manufactured as single standalone components. They are always integrated in groups in an IC,

but for the sake of clarity, they are represented as separate blocks. These components require a DC voltage, which may or may not be represented on the schematic. These voltages might be different depending on the internal structure and technology used between different family types. Detailed info on this can be found in the component's datasheet provided by the manufacturer.

10.1 Relays

A relay is an electro mechanical device which is commonly used to connect two different circuits. It can connect a low voltage circuit to a high voltage circuit or a low current circuit to a high current circuit or simply to isolate two circuits.

The simplest relay has one set of contacts (commonly called "change-over" contacts). Inside the relay is a coil (called a solenoid) and when the coil is energised, the centre core of the solenoid becomes magnetised and moves an arm closer to the coil. A "contact" is connected to this arm and the contact touches another contact to complete a circuit. The contacts are labeled "common" for the moving contact, "normally open" and "normally closed." This can be seen in diagram 10.2 a:



10.2. a - internal structure and relay symbol b - relay with three pairs of contacts

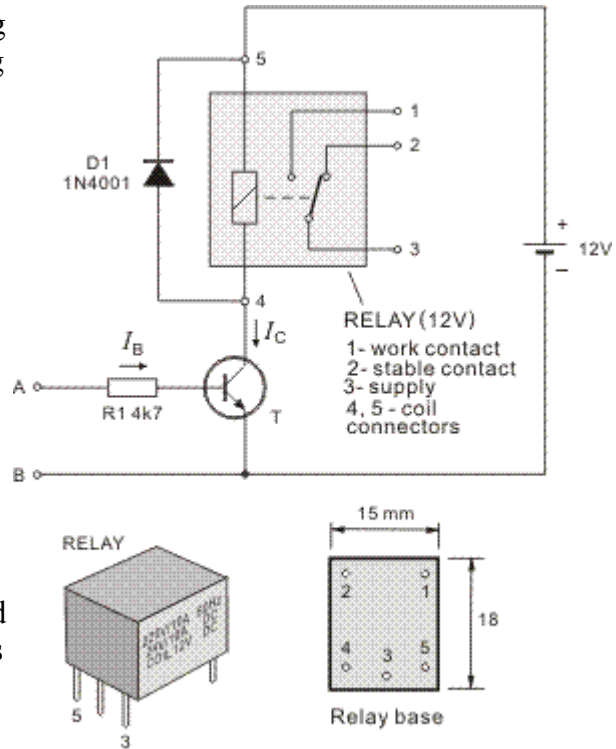
A relay can be connected as the collector load of a transistor, as shown on 10.3. When sufficient collector current flows in the transistor, the relay is activated and any device connected to the contacts will be operational.

Since a relay is an electro mechanic component which is consisted of moving parts, it has a limited operational life span, and cannot be used for rapid switching. It would not be very effective using it in a, for example, light show which has frequent switching frequency (several hundreds or thousands times per hour). Each opening and closing of the contact is followed by sparks which would dramatically shorten the life of such device.

Coil values are “input values” or voltage and resistance values at which relay draws the lever and switches. Usual coil voltages are 3V, 5V, 6V, 12V and 24V. They can be found printed on the relay's housing. These are all DC voltages, but there are AC voltage designed relays with 230V/250V. The current taken by the relay depends on the resistance of the coil. The coil resistance can be measured with a multimeter. Current flowing through the coil is calculated using Ohm's law, by dividing the relay's voltage by its resistance. For example a 12v relay has a coil resistance of 300 Ohm, which means the current flow is:
 $I = U/R = 12/300 = 40\text{mA}$.

2. Voltage on relay's contacts, also marked on the housing, is the maximum value allowed. Over-voltage will cause sparks inside the relay and possibly damage the contacts.

The maximum current rating for a relay is marked on the housing with all the other information. It is usually higher than 1A.



10.3. Relay as an collector transistor load

11. Checking Components

So you've put a circuit together and as far as you know everything appears to be ok, but it doesn't work as expected. Even worse, it refuses to give any signs of life. What do you do? First, check the circuit for mechanical failures, like non-connected wires, broken vias on the board (these are holes on the printed circuit board that have a metal coating down the length of the hole to connect one side of the board to the other), bad battery contacts inside the case, broken pins on a component, cold solder joints, etc.

If this doesn't come up with a result, you should compare values of components with the schematic.

You may have put a component in the wrong place, or read values the wrong way. Maybe you forgot k in front of Ohms. Maybe you connected the supply to the wrong pin of an IC.

The next step is to test each component on the board.

Start troubleshooting by measuring DC voltages at certain points of the board, and comparing these values to the schematic. So, by knowing the operation of the circuit you start the process of elimination to find the “suspect” component.

If there are several “suspects”, and this is not a rare occurrence in complex devices, the testing is divided into groups of components. You start checking in reverse soldering order, this means you start with components last soldered, because those are the most sensitive components on the circuit like integrated circuits, transistors, diodes, etc.

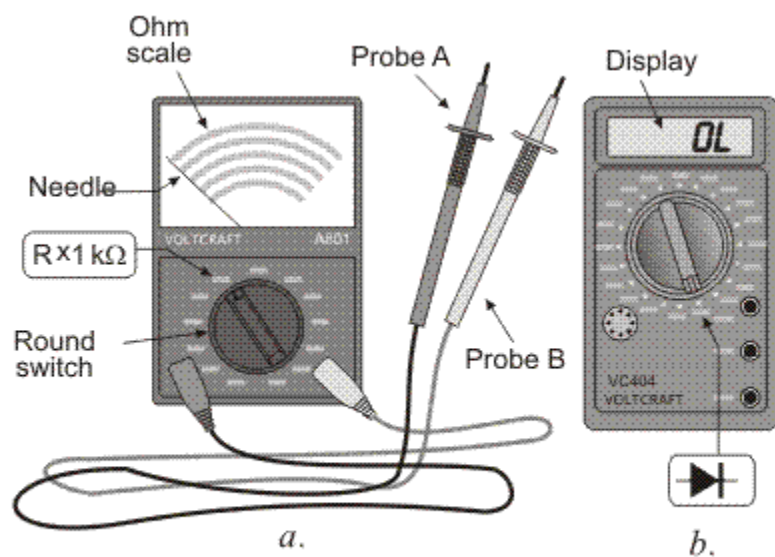
The fastest and simplest method to troubleshoot is to use an “ohm-meter.”

In most cases you don't have an ohm-meter by itself as it is usually added to an ammeter and voltmeter in one instrument, called AVO meter or multimeter.

The safest and most accurate method is to desolder the component from the board when testing it, because other components could lead to a wrong diagnosis, so you have to be very careful when testing in-circuit.

Ok, you should know something about multimeters now. There are two kinds: analog and digital. Analog ones are items of the past, and since they use a needle to tell you values, it can be difficult determining the right value. Digital meters, on the other hand have a display. You should go for this type, although both come in different sizes and with different ranges. Their price is from several dollars, to several hundreds of dollars for really good professional types.

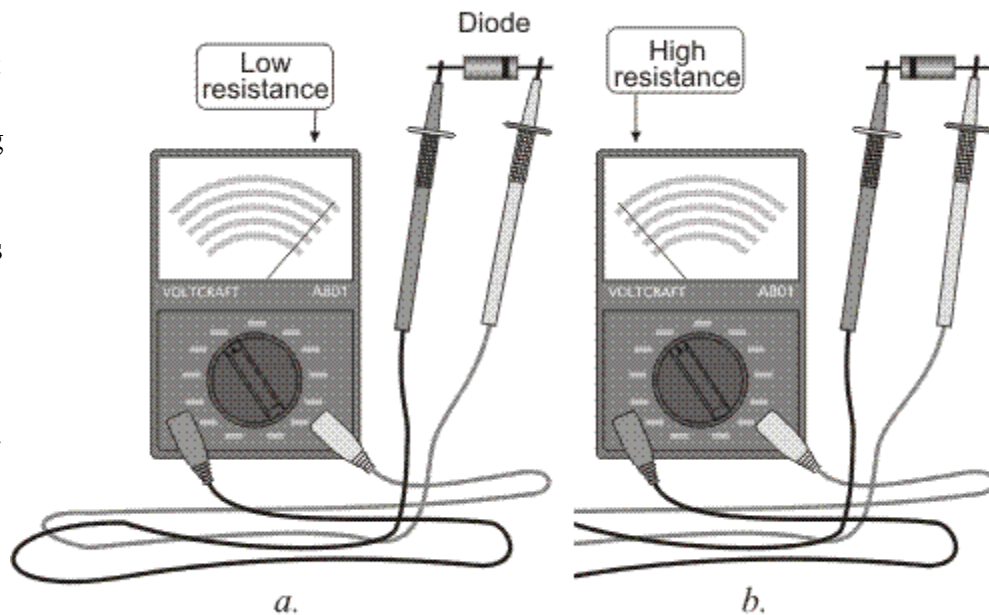
Two instruments are shown in 11.1.



11.1. Multimeter (AVO meter):
a - analog, b - digital

11.1 Diodes and Transistors

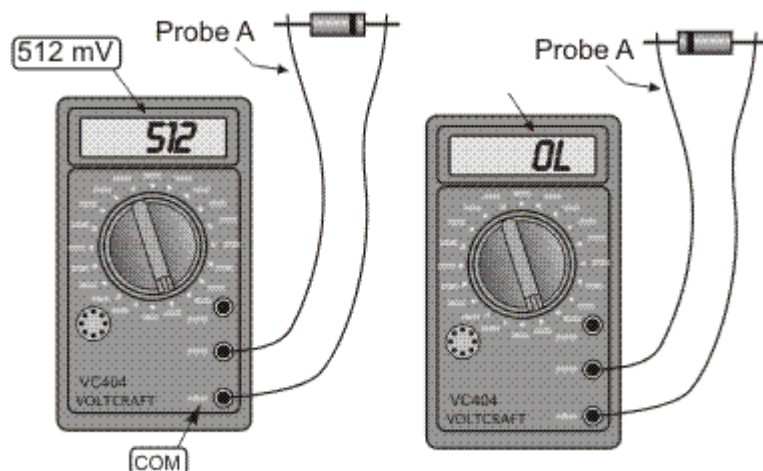
When using an analog instrument to test a diode, the needle will swing almost fully across the scale when the diode is placed in one direction and hardly move when the diode is reversed. The needle does not measure the resistance of the diode but rather the flow of current in one direction and no current-flow in the other direction.



11.2. Diode testing using an analog instrument

If the value is equal to or near equal, either low or high in both directions, the diode is faulty, and should be replaced.

Digital instruments have a position on the dial to measure diodes, as shown in 11.1b. When we connect probes to each other, the multimeter should buzz, which signals a short circuit, and display tells 0. When we separate the probes the buzzing stops, and a symbol for open circuit is displayed (this can be either 0L or 1). Now we connect probes to the diode (11.3a). Then we reverse the diode and connect it again (11.3b). If the measured diode was ok, one of the two measurements would have shown a value which represents a minimum voltage that could be conducted through the diode (between 400mV and



11.3. Diode testing using a digital instrument

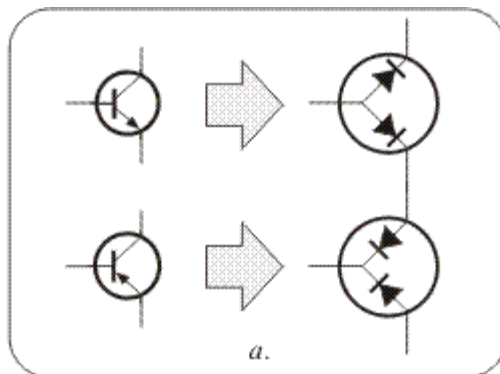
800mV), and the anode is the end of the diode which is connected to probe A (red one). The diode is faulty if you hear a buzz (closed circuit) or some value which represents infinity. Transistors are tested in a similar fashion, since they act as two connected diodes. According to 11.4b, the positive probe is connected to the base, and the negative probe is first connected to the collector and then the emitter. In both cases the resistance should be low. After that, you do the same thing, only with switched probes. The negative probe is connected to the base and you test the collector and emitter with a positive probe.

Both cases should produce a high value on the meter.

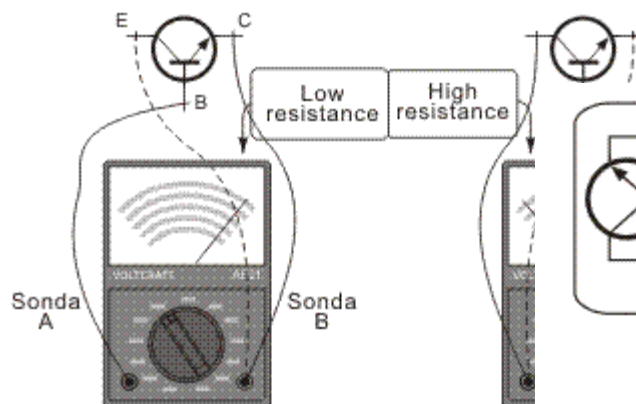
When testing PNP transistors, all steps are the same, but the measurements should be opposite: on 11.4a they are high, and on 11.4c they are low.

If you test transistors using a digital instrument, the process remains similar to the one with diodes. Each diode should produce a value between 400mV and 800mV. Many modern digital multimeters have a socket for testing transistors. There

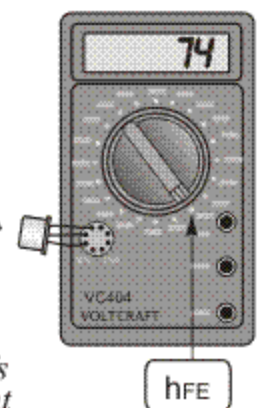
is, as displayed on 11.5, a special socket where low and medium power transistors fit. If you need to test high power transistors, thin wires (0.8mm) should be soldered to transistor's pins and then plugged into the socket. As displayed on 11.5, a transistor is plugged into the socket according to its



type (PNP or NPN) and the switch with a hFE marking is brought into position. If the transistor works, the display shows a value which represents the current amplification coefficient. If, for example, a transistor is tested, and the display shows 74, this means the collector current is 74 times higher than the base current.



c. 11.5. Measuring the transistor's current amplification coefficient



11.2 Transformers and coils

Transformers are tested by measuring the resistance of the copper wire on the primary and secondary. Since the primary has more turns than the secondary, and is wound using a thinner wire, its resistance is higher, and its value is in range of tens of ohms (in high power transformers) to several hundreds of ohms.

Secondary resistance is lower and is in range between several ohms to several tens of ohms, where the principle of inverse relations is still in place, high power means low resistance.

If the multimeter shows an infinite value, it means the coil is either poorly connected or the turns are disconnected at some point.

Coils can be tested in the same way as transformers – through their resistance. All principles remain the same as with transformers. Infinite resistance means an open winding.

11.3 Capacitors

Capacitors should produce an infinite reading on a multimeter. Exceptions are electrolytics and very high value block capacitors. When the positive end of an electrolytic capacitor is connected to the positive probe of an analog instrument, and a negative end to a negative probe, the needle moves slightly and gradually comes back towards infinity. This is proof the capacitor is ok, and the needle's movement is charge being stored in the capacitor. (Even small capacitors get charged while testing.)

Variable capacitors are tested by connecting an ohm-meter to them, and turning the rotor. The needle should point to infinity at all times, because any other value means the plates of the rotor and stator are touching at some point.

There are digital meters that have the ability to measure capacitance, which simplifies the process. With this said, it is worth mentioning that capacitors have considerably wider tolerance than resistors, (about 20%).

11.4 Potentiometers

To test a potentiometer, (pot), or a variable resistor, the process is rather simple – you connect the component to the probes of a meter set to ohms and turn the shaft.

(A “noisy” pot can be repaired using a special spray.)

11.5 Speakers and headphones

When testing speakers, their voice-coil can be between 1.5 and 32 Ohms. The value marked on the speaker is an impedance value and the actual DC resistance will be lower. When measuring a speaker with an analogue meter, you should hear a click when the probes are connected.

12. Conductivity probe

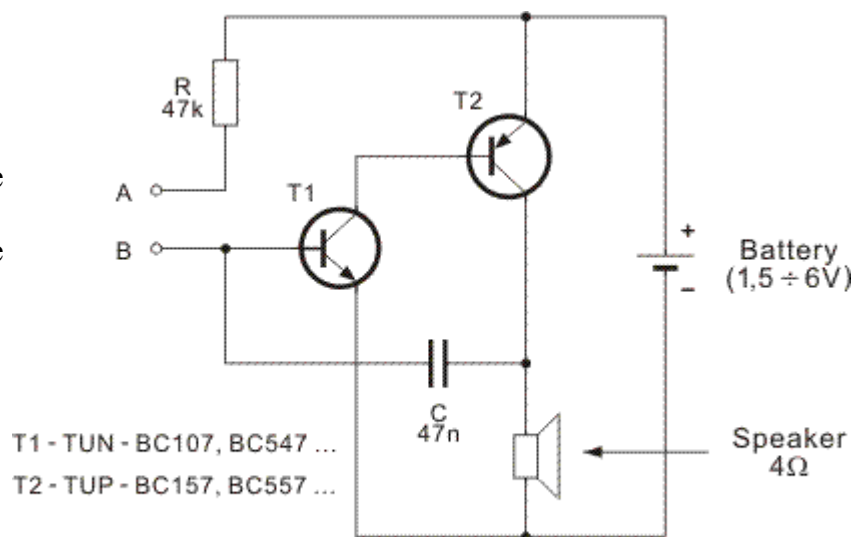
Conductivity tester is a simple, but very important instrument, which is able to test for faults many components like: diodes, transistors, coils, transformers, speakers and headphones, capacitors, switches, jumpers, cables and many other different electronic components. This method is a lot faster and straightforward than it is using some “off the shelf” instrument. Schematic for this device is on 12.1a. It is called a relaxation audio oscillator. When you connect points A and B using a piece of copper wire, a variable current flows through the transistors as sequences of impulses. This means that immediately upon connecting the points A and B, current level rapidly rises to some destined maximum value, and then drops to zero. For certain amount of time there is no current, after which it rises again rapidly, and whole cycle repeats itself. Since relation of times when current is flowing and when it is not is highly in favor of the later, this kind of current is called the spike impulse current. Collector current of a T2 transistor flows through the speaker which generates sound, whose base frequency could be calculated using this approximate equation.

$$f = \frac{1,6}{RC}$$

In our case $R=47 \text{ k}\Omega$ and $C=47 \text{ nF}$, which means:

$$f = \frac{1,6}{47 \cdot 10^3 \cdot 47 \cdot 10^{-9}} = 724 \text{ Hz.}$$

From the equation above, it is clear that varying of the frequency is possible by varying the resistor or capacitor value. Frequency rise is achieved by lowering the resistance or capacitance of the circuit, and vice versa, rising the values of the resistor or capacitor, lowers the oscillator frequency. Active variation of the frequency base is possible by replacing the resistor with a several hundred kilohm trimmer potentiometer. If such



12.1. Schematic of a conductivity tester

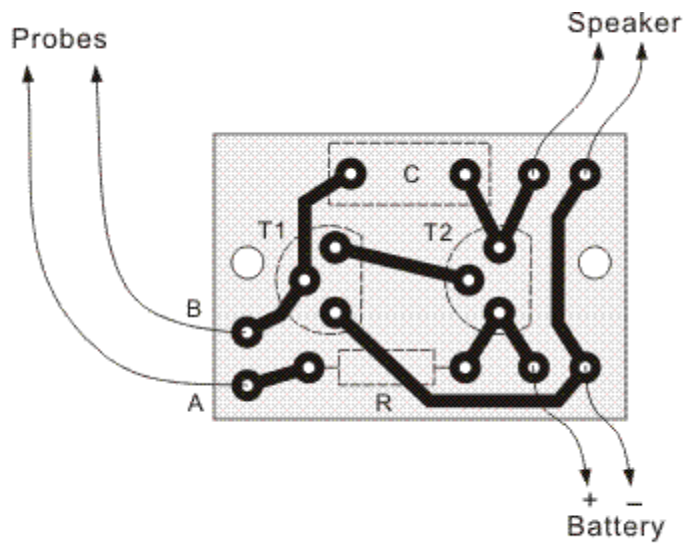
modification of the circuit was needed, special care must be taken not to set the trimmer into its lowest position since this means zero resistance, and that could burn the transistors. To avoid unnecessary care and further complicating the operation of this straightforward device, low value resistor could be connected to the trimmer in series. This resistor would act as a protection for transistors inside of the circuit since it facilitates a minimum resistance, and thus doesn't leave transistors bare in the frying pan when the trimmer is in its lowest position.

In this example we used an 1.5V battery for supply, but it is possible to plug this instrument on any battery between 1.5V and 9V.

Current flowing through the component that is being tested is lower than $I=U/R$, where U is the voltage of the supply battery, and R is the resistance of the resistor in the base circuit. In our example, these values are $U=1,5\text{ V}$ i $R=47\text{ kW}$, which means that current flow is $I=32\text{ micro amperes}$, which is very low, so tested component is safe from harm from this device.

Oscillator's printed board design is on 12.2. This is viewed from the copper plated side of the board, components are placed on the other side, so their positions are marked in dotted lines.

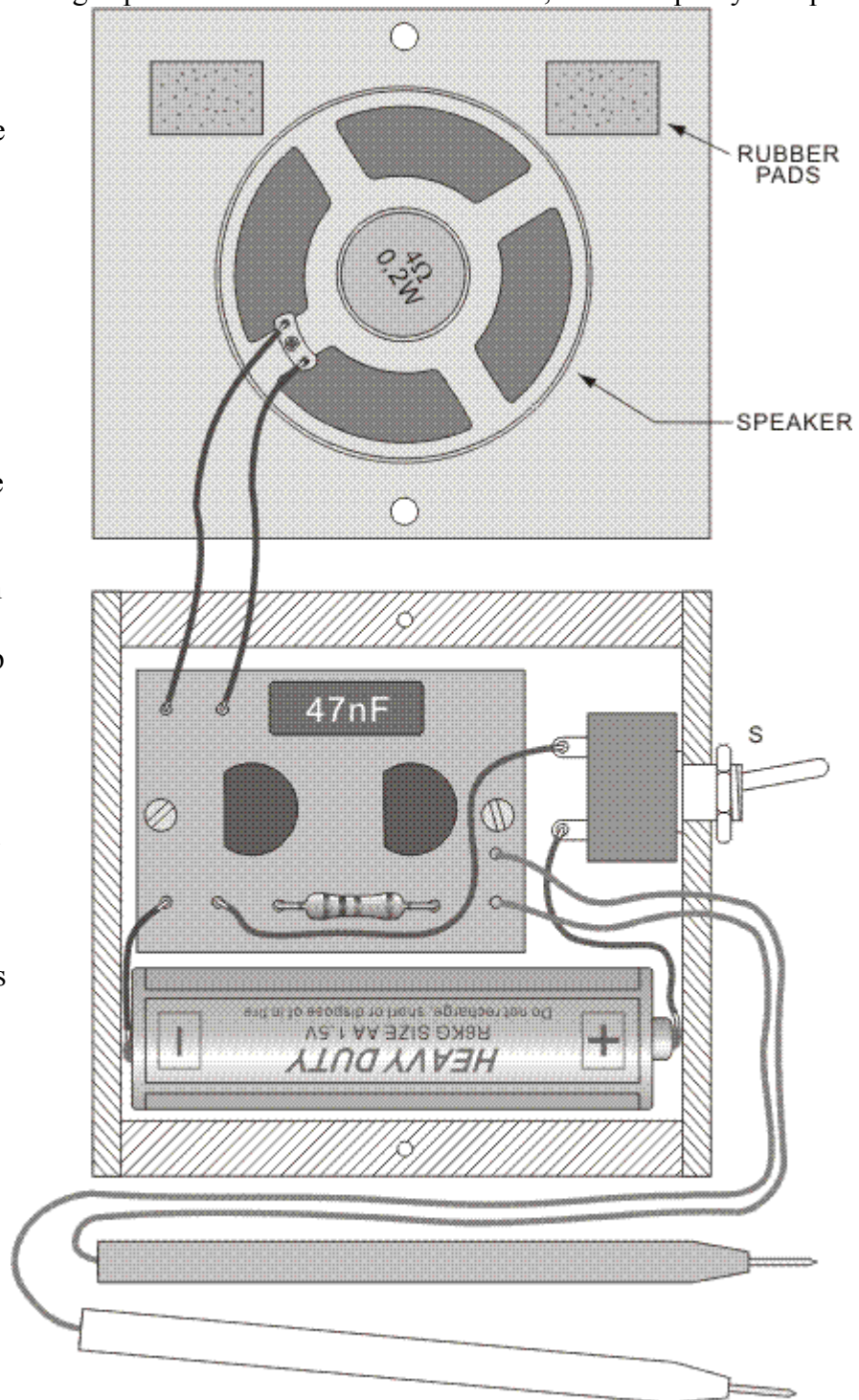
Component side of the board is on 12.2.



12.2. Tester's printed circuit board with components placement

Printed board, battery and the speaker are placed in a small box, as shown on 12.3. Miniature speaker is fixed to the upper pane of the box using two wood screws. It is connected to the circuit board using two threaded isolated wires. Same wires are used for all other connections as well. Battery is connected to the board using these wires, for example. In our example, wires are soldered directly to the poles of the battery, and the board fixed inside of the box using wood screws and two rectangular wooden pads glued to the bottom of the box, leaving just enough space to squeeze the battery in. These are not proper

solutions, they are cheap “hacks” used when other options are limited. But these are functional for people who always have their trusty soldering iron at hand. What would be a proper solution? Buying a battery holder (with enough battery slots as needed) or battery clips (for those square 9V batteries) would simplify the process of changing the battery, although this circuit is very low in power consumption. Other thing is plastic or metal mounts for boards, these are pretty cheap and you should keep them at hand in your “junk box” when experimenting with electronics. On the front side of the box, we drilled two holes, one for the switch and the other for wires which hold probes on their ends. Probes are cheap components and come in various shapes and sizes with various purposes in mind. Since we've been applying dirty methods, like soldering the battery, there is no reason why we should back from building our own probes now. Any old marker-pen will do, just slip thicker copper wire through it's center, and sand/grind/cut protruding ends into a pointy tip. It is advisable to make probes in different colors, red and black are dominant standards for distinguishing them. Positive probe (red) is connected to point A, and negative one (black) is connected to the point B. You could use alligator clips instead of probes, for example, this would leave your hands free for other purposes, but for some precise testing of the on-board components, go with the more precise probes we already mentioned. Give your new instrument



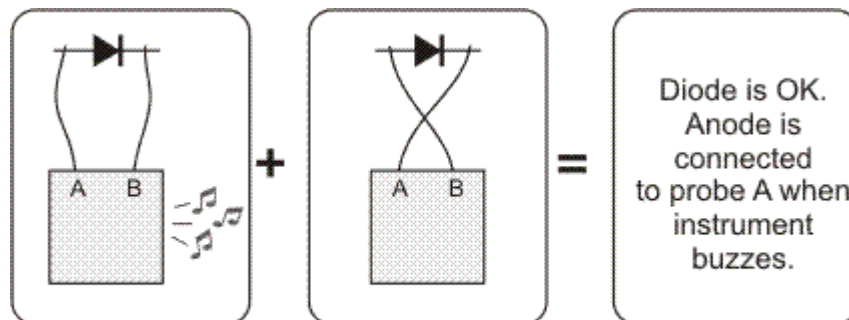
12.3. Conductivity tester

the initial self-test (battery might be empty, or some other unexpected thing happened) by connecting the probe tips together. If sound is heard from the speaker, everything is fine and ready for work.

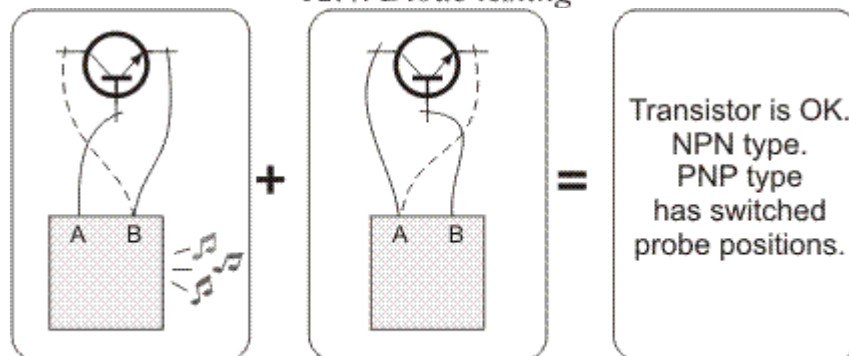
Ok, everything is working, now you want to play with your new toy. Check, for example, conductivity of your own body. Hold probe tips between thumb and index finger of your left and right hand. What you hear is a sound whose level and especially frequency depend on your skin moistness. Wow, now instrument could be used as a very crude and inaccurate lie detector. This probably wouldn't be accepted in a court of law, but may be an interesting game you play on your friends. "Suspect" holds in his/hers hands probes which could be made of a metal pipe for this occasion. Pipe should be wide enough so that a large portion of palm surface is actually in contact with metal. When the suspect starts dodging questions or lying, his palms start sweating more than usual, and the tone produced by our "lie detector" is higher than usual.

12.1 Semiconductors check

To test diodes using this circuit, we fall back to the diode theory of operation: when anode is positive comparing to the cathode (red probe on anode, black on cathode), whole diode acts as a low value resistor, which means that speaker sound is higher than usual. On the other hand, in the opposite direction, sound is lower because in that direction diode acts as a high value resistor. Testing process is shown on 12.4.



12.4. Diode testing

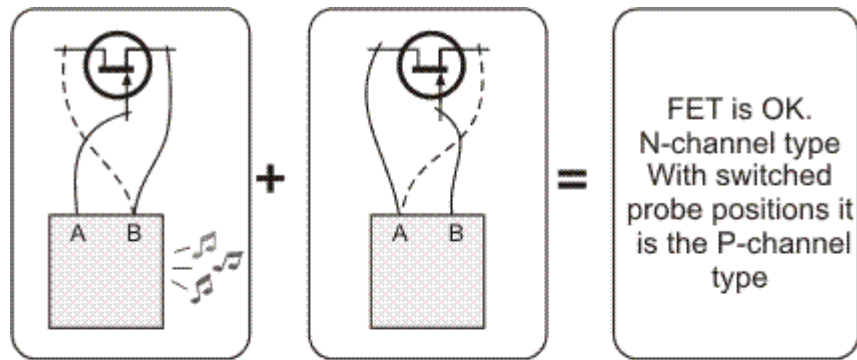


12.5. Bipolar transistor testing

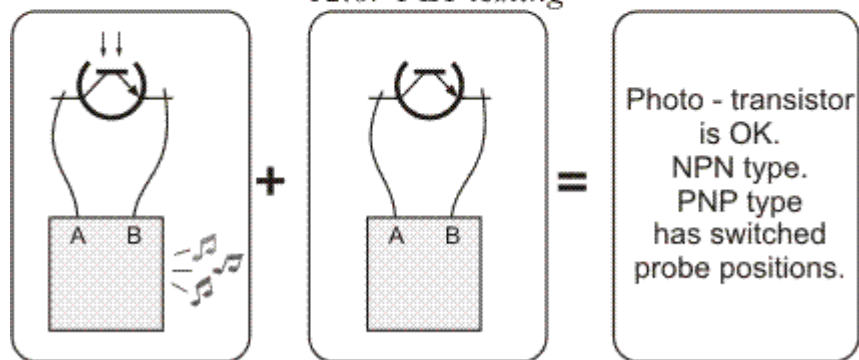
DC transistor acts in the same fashion as two connected diodes (11.4a). If both diodes are functional, transistor is functional as well as shown on 12.5. As you can see, probe A is

connected to the base, and then probe B is connected first to the emitter, and then to the collector. In both cases, if the transistor is ok, “music” would have been heard. We then switch probe connections, A goes where B was connected to and vice versa, if there is no music now, everything is in order. So, transistor is faulty if speaker remains silent in the first two measurements, or if it “plays” in one of the second two measurements.

FET testing is done in similar fashion as testing the bipolar transistors, which is shown on 12.6.



12.6. FET testing



12.7. Photo transistor testing

One principle that is applicable when testing the photo resistors, photo transistors and diodes is NL-NM (or, No Light – No Music). Probe A is connected to the collector of the transistor, or diode's anode or one side of the photo resistor, and the other one is connected to transistor's emitter or diode's cathode or the other resistor's side and some kind of sound should be heard from the speaker. If this continues when the component is shadowed using your palm, everything is in functional order. We displayed graphically the method of testing photo sensitive components on 12.7.

12.2 Checking other components

Many other components may be tested using this instrument. Base rule is: if component is intended to conduct electricity, sound will be heard. This is the case with resistors, coils, transformers, fuses, closed switches. If component doesn't conduct electricity, like capacitors, or open switches, or two copper wires on the circuit board which shouldn't be connected, then music would have not been heard.

When testing different resistors, it is apparent that different resistance values give different output sound. So with some experience using this instrument on various resistors it will be possible to tell the resistance of the resistor in question from only the generated sound. This may be easier and more accurately done using regular ohmmeter on your multimeter, but your nerd level will certainly rise sky high if you are able to tell resistor's value from bare sound.

Components which have coils in them, like different electro motors, headphones, speakers, transformers and such conduct electricity, so absence of sound while testing tells of some coil connection failure. With transformers with several secondary coils there is a possibility to find beginning and the end of each of them. And from the sound frequency one is possible to tell which coil is primary and which is secondary.

Functional capacitor will generate no music. An exception are electrolytic and block capacitors, especially the larger ones. Tone generated by connecting these capacitors to the instrument will change in level and frequency and fade until completely off when capacitor is discharged.

Length of playing depends on the capacitance of the component, where higher values give longer sound time, which allows for a crude approximation of the component's capacitance.

The end